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USE OF SEWAGE SLUDGE FOR FOREST-TREE SEEDLING PRODUCTION

by

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Research was undertaken to determine the beneficial and harmful effects of using dewatered, digested sewage sludge in: 1) containerized production of forest tree seedlings, 2) tree seedling production in a conventional outdoor nursery, 3) establishment and growth of transplanted bare-root coniferous seedlings grown in the field as Christmas trees, and 4) formation and survival of mycorrhizae on forest trees and soybeans.

Tree seedling performance was evaluated relative to the abundances of required nutrients in sludge as compared with conventional fertilization practices. Toxicities of various elements were determined, as were sludge-induced nutrient deficiencies associated with various sludge types and application rates. Optimum loading rates were determined to maximize seedling survival and growth in the field and to minimize the risks associated with ammonia and heavy-metal toxicities.

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FOREWORD

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water systems. Under a mandate of national environmental laws, the agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. The Clean Water Act, the Safe Drinking Water Act, and the Toxics Substances Control Act are three of the major congressional laws that provide the framework for restoring and maintaining the integrity of our Nation's water, for preserving and enhancing the water we drink, and for protecting the environment from toxic substances. These laws direct the EPA to perform research to define our environmental problems, measure the impacts, and search for solutions.

The Water Engineering Research Laboratory is that component of EPA's Research and Development program concerned with preventing, treating, and managing municipal and industrial wastewater discharges; establishing practices to control and remove contaminants from drinking water and to prevent its deterioration during storage and distribution; and assessing the nature and controllability of releases of toxic substances to the air, water, and land from manufacturing processes and subsequent product uses. This publication is one of the products of that research and provides a vital communication link between the researcher and the user community.

This report concerns both the safe discard and disposal of potentially injurious substances in human and industrial wastes and their possible uses as valuable resources.

Francis T. Mayo, Director
Water Engineering Research Laboratory

PREFACE

Two of the major environmental problems that have received much public attention in recent years are the disposal of sewage sludge and soil deterioration. Solving one problem may ultimately solve the other.

In recent years, municipalities in the United States have faced the dilemma of how to handle large amounts of municipal sewage generated by our increasing population. In the United States, about 10,000 metric tons of dry sludge solids are produced daily. This production level will undoubtedly increase in the future, because compliance with the Federal Water Pollution Control Act Amendment of 1972 requires improved treatment of wastewaters by both large and small municipalities. The problem of sludge disposal is further compounded by the lack of alternative disposal methods.

Incineration of sludge solids has often been found to be less than environmentally acceptable and restricted by the availability of natural gas. Sludge disposal in sanitary landfills has resulted in severe environmental and health problems. Sludge application on agricultural land used for food and feed production has suffered because of a lack of public acceptance and the potential for producing toxic levels of some sludge constituents in foodchain crops.

Treated sewage sludge has been applied to agricultural soils and to toxic spoil materials remaining from strip mining. Though the fertilizer value of sewage sludge has been established, many questions remain unanswered about its safety, efficiency, and best use in land disposal.

As an alternative to the land application of sewage sludge for food and forage crop production, this material might be used more efficiently and effectively to produce non-foodchain crops such as forest trees for fiber, beauty, recreation, fuel, construction, etc. Trees have diverse uses, both presently and in the immediate future. Containerized seedling production will become a routine practice in the future. Sludge application to such nonfoodchain crops may be particularly useful for sludges that are difficult to dispose of.

ABSTRACT

Research was undertaken to determine the beneficial and harmful effects of using dewatered, digested sewage sludge in: 1) containerized production of forest tree seedlings, 2) tree seedling production in a conventional outdoor nursery, 3) establishment and growth of transplanted bare-root coniferous seedlings grown in the field as Christmas trees, and 4) formation and survival of mycorrhizae on forest trees and soybeans.

Tree seedling performance was evaluated relative to the abundances of required nutrients in sludge as compared with conventional fertilization practices. Toxicities of various elements were determined, as were sludge-induced nutrient deficiencies associated with various sludge types and application rates. Optimum loading rates were determined to maximize seedling survival and growth in the field and to minimize the risks associated with ammonia and heavy-metal toxicities.

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LIST OF ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

CEC -- cation exchange capacity (milliequivalents per 100 g of soil)
cm -- centimeter
CMP -- calcium monophosphate ($Ca(H_2PO_4)_2 \cdot H_2O$)
EC -- exchangeable alkaline cations
g -- gram
ha -- hectare
kg -- kilogram
l -- liter
LSD -- least significant difference
m -- meter
meq -- milliequivalents
mg -- milligram
mm -- millimeter
MR -- mycorrhizal
MT -- metric ton
NMR -- nonmycorrhizal
$\#/m^2$ -- number per square meter
O. M. -- organic matter
ppm -- parts per million
R^2 -- coefficient of correlation
S:R -- shoot to root ratio
TSP -- triple super phosphate
VA -- vesicular-arbuscular
v/v -- volume per volume
w/w -- weight per weight

SYMBOLS

Θ -- soil water content (g/g dry soil)

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SECTION 1

INTRODUCTION

The studies described herein were conducted to ascertain the desirability of using sewage sludge for tree production. Some sludges contain materials that, when used on agricultural or garden crops, can present human or plant toxicological problems. The intent of these studies was to learn if such "undesirable" sludges might be used safely to produce non-foodchain crops.

Disposal of municipal sewage sludge by application on land used for food production is restricted by the relatively small amounts of sludge needed each year to meet the nitrogen or phosphorus needs of annual crops. Applications are limited in the long term by the accumulation of potentially toxic sludge-borne heavy metals in soil that may find their way into the food chain. But, on land committed to non-food crops, heavier rates might be used, limited only by deleterious effects on vegetation or excessive transport of pollutants away from the treated area.

Agricultural use of sewage sludge has been practiced for several years, but experience has suggested caution. Urban sludges contain varying amounts of heavy metals that can accumulate in soil with continual or massive applications and can render them exhausted or even sterile because of toxic effects. Thus along with recent interest in the land application of sewage sludge has come considerable study on its interactions with associated soil factors, soil flora and fauna responses, and higher plant responses.

Perennial crops such as forests and Christmas trees require different management techniques than field crops and vegetables for their production. Similarly, their responses to environmental stresses and biologic influences are in many ways unlike those of cultivated crops used as food and feed bases. Although a great amount of sludge research has been initiated in recent years on field crops such as corn and soybeans, very little has concerned trees. Just as plants differ in their growth patterns and responses to stimuli, sludge research on trees is unique, particularly in light of the lack of such research. Sludge research on trees is different because:

1. Very little is known about sludge constituent availability in nurseries and different forest soils regarding nutritional status and demands of various tree species.
2. Nutrient requirements of trees in the nursery are greater than those of field crops, but requirements of trees in the forest are less than those of field crops. The 3.5 million

dry tons of sludge produced annually in the U.S. might be used more efficiently energywise and certainly more safely and with fewer restrictions and constraints on non-foodchain crops.

3. Site preparation following logging has seldom involved fertilization even though increased fertility increases survival and growth characteristics of a new forest. Economics has prohibited fertilization.

4. Economics (cost-benefit) of forest tree fertilization using sludge as a soil conditioner-fertilizer has received little to no consideration for:

   a. conifer containerized production
   b. hardwood containerized production
   c. outdoor nursery production of tree seedlings
   d. site preparation prior to stand regeneration whether by natural or artificial means
   e. Christmas trees and ornamentals production

5. Sludge has not been studied adequately relative to nutrient cycling in forest ecosystems.

Fertilization has been investigated in terms of commercially-produced fertilizers and their effects on trees. Sludge could prove to be a more energy-efficient, adequate, and easily obtainable amendment and/or fertilizer substitute whereby better use could be made of valuable resources. Tree fertilization effects such as the following have been observed:

1. Moderate fertilization increases seedling survival and growth rates in both greenhouse and outdoor nurseries.

2. Fertilization of forests has to date been uneconomical, but future timber values, land costs, fuel shortages and improved planting stock warrant a new appraisal of the practice.

3. Fertilization of pines, true firs, Douglas-fir, and certain spruces grown for Christmas trees results in more dense foliage and deeper, more attractive color.

4. Nursery soils are rapidly depleted of minerals due to leaching and removal of accumulated nutrients upon harvesting.

5. Different levels of fertility are optimally appropriate for different tree species.

6. Fertilization of trees in seed orchards results in increased seed production.

7. Increasing organic matter in forest soils with the concurrent introduction of certain fungi stimulates better seedling sur-

vival and growth due to an increase in mycorrhizae. Mycorrhizae increase the root absorption capacity of a plant and function most significantly in phosphorus nutrition.

8. Nitrate nitrogen is used more successfully by trees at lower soil pH. Forest soils tend toward acidity; therefore, sludge could be used on forest soils very efficiently in terms of nitrogen utilization.

9. Forest trees require about 45 lb of nitrogen per acre per year and return all but 8 lb via leaf fall (hardwoods). Sludge could serve as a good catalyst for a self perpetuating regime. There is an annual nitrogen depletion in forests of the U.S. of about 5 lb/acre/year.

10. The total use of calcium and phosphorus among conifers averages about 60 and 10 lb/acre, respectively. Hardwoods such as beech and oak use Ca and P at about 80 and 12 lb/acre, respectively. Sludge could probably supply enough of each for a complete tree crop rotation.

On certain sites, especially moderately dry ones, nitrogen fertilization can result in 15 to 30% greater leader growth in white pine, white spruce, and Douglas-fir over 3 years, probably resulting in a rotation shortened by at least a year. This would decrease production costs by more than $310/acre, get the crop to market sooner, and permit subsequent crop establishment a year or so earlier. The value of nitrogen alone in sludge is near $45/acre (using 2.5 dry tons/acre) which places gains near $350/acre over no fertilization at all. Sludge spreading costs would be less than $75/acre, resulting in a net gain of $280/acre just due to increased height growth rates.

An additional benefit is that of increasing the quality of trees by inducing increases in foliage weights and density from nitrogen applications of 150 lb/acre. Foliage weight increases of 5 to 16%/year occur on Fraser fir, white spruce, Norway spruce, white pine, Scotch pine and Douglas-fir with one fertilizer application 1 year after planting. This benefit, plus better foliage color and an increased number of whorl limbs resulting from fertilization, place a tree in a higher grade, making it more valuable in both wholesale and retail markets. Overall, the use of sludge in Christmas tree production should result in a net gain of more than $2000/acre over the rotation or a projected benefit-cost ratio of 30 to 1.

Nationwide there are some 450,000 acres of commercial Christmas tree plantations. The use of sludge on the crop could result in a net gain for the wholesale area of the industry of as much as $9 million/year. If one considers an average rotation with good management as 10 years, then 10% of the total area, or 45,000 acres, could theoretically accommodate more than 100,000 tons of sludge yearly.

The feasibility and economic justification of forest fertilization has been studied for decades in Europe and more recently in the United States.

There are few who feel enough information is presently available in this country to recommend for or against the practice as an integral part of routine management plans, but large timber companies in the West are currently fertilizing forests because it is felt that "it pays". Approximately 16.5 million acres, or 1.25% of the forest land, in West Germany and Scandinavia are fertilized annually.

It has been shown with slash pine in the South that fertilizing at planting time results in a rate of return between 11 and 25%, depending on initial site quality, with fertilization costs of $28 to $30/acre, and trees are harvested at age 20. Fertilizing 15-year-old stands results in return rates between 9 and 35%, depending again on site quality, with a cost of $28 to $39/acre, and trees are harvested at age 25. Although the return rate of the latter system is higher, average final pulpwood yields with fertilization at planting were 2 cords/acre more. Fertilizing at planting time with 45 lb each of N and P resulted in a yield increase of 8 cords/acre at harvest (age 20). This could mean a net gain of more than $100/acre to the grower. A sludge application of 2 tons/acre (dry matter) could be a desirable alternative as a fertilizer source.

There is a great deal of variability in response to fertilization among and within timber species. Douglas-fir yields have been increased as much as 30% with commercial fertilizer. Yellow-poplar fertilized in a small-saw-timber or pole stage increased in volume by nearly 80% during a 6-year period when fertilized with 1125 lb of N. This yield response represented a compound growth rate of more than 10% annually. A sludge application of 40 dry tons/acre at planting time should result in similar or even greater benefits.

It has been shown that plots fertilized with 396 kg/ha (approx. 2.2 tons/acre) of diammonium phosphate produced nearly twice the tree biomass of unfertilized plots after 5 years of growth. Phosphorus as P_2O_5 applied in sludge at the appropriate rate could have a similar impact on high-density, short-rotation tree crop yields for fuel and/or fiber.

Normal and successful nursery practice requires the use of fertilizer in seedbed preparation and periodically during seedling production. Depending on the species grown, as much as 224 lb of available nitrogen, 71 lb of phosphorus, 109 lb of potassium, and 131 lb of calcium are removed per acre of nursery bed over a 2-year period by seedlings eventually harvested as 2-0 stock. The 1-0 seedling density was 145 and the 2-0 density, 100 seedlings /sq. ft. The cost of the fertilizer necessary to replace the loss would exceed $10 to $20/acre as more material must be applied than is actually taken up to account for leaching and soil adsorption. Sludge applied at the rate of 50-100 dry tons/acre could supply a significant portion of the nutritive requirements of the crop, increase soil moisture retention, foster slow release of plant nutrients, and provide a significant demand for sludge in certain areas.

This study deals with the use of sludge in three non-food systems: a) Christmas tree production, b) tree nursery seedling production, and c) containerized tree seedling production. In Christmas tree production, land is prepared once every 8 or 10 years and can be fertilized before or after planting. In many cases, no fertilizers are added. In this system, sludge could be applied before soil preparation to provide nutrients that would be released more slowly than from inorganic fertilizers. Thus, the first objective of this study is to determine whether increasing sludge rates have beneficial, harmful, or no effects on the growth of various tree species, and whether they have secondary effects on weed growth.

In nursery bed seedling production, lighter, sandy soils are usually selected because of their better drainage and properties as a rooting medium. Such soils normally require supplements of organic matter to maintain nutrient and water-holding capacity. The second objective of this study is therefore to determine whether heavy applications of sludge can improve organic matter content, soil properties, and seedling growth.

Production of containerized tree seedlings in greenhouses is a developing and popular technology that now provides most of the privately planted forest seedlings in some areas. Such intensively-grown trees require optimum fertilization of their artificial rooting medium. Thus, the third objective of this study is to determine whether supplemental sludge amendments can improve growth in such containers.

In addition, certain effects of sludge on phosphorus nutrition are examined in this report. Although sludge contains substantial amounts of P, its availability to plants may vary with the treatment method used to remove it from wastewater. In addition, toxic components of sludge may affect plant uptake of P by inhibiting the development and activity of mycorrhizal fungi (root-infecting symbionts). This aspect of sludge application is also studied.

Most recent research has focused on the elemental constituency of plant parts and plant health as it relates to the heavy metal content of the sludge applied. A small amount of work concerns the response of soil fauna, notably earthworms (Helmke et al., 1979), and another small concern has involved the physical and chemical reaction involved (Epstein et al., 1976) in soil-sludge mixtures. Virtually ignored has been the microbiological implications of the situation, although recent publications point to increased interest in this area (Beck, 1979; Bhat, 1979; Bollag, 1979; Cole, 1979; Lance, 1978; Orchard, 1979; Sakeguchi, 1979; Spitko and Manning, 1979; Sterrit, 1980).

Vesicular-arbuscular (VA) mycorrhizal fungi are known to improve plant growth by increasing the uptake of plant nutrients, particularly phosphorus (Rhodes & Gerdemann, 1980). Spore germination of certain species of VA fungi has been shown to be adversely influenced by at least three heavy metals -- Mn, Cu, and Zn (McIlveen & Cole, 1979; Hepper & Smith, 1976; Hepper, 1979) -- which are often present in high concentrations in sludge. Such inhibition of mycorrhizal fungus spore germination could result in limited mycorrhizal development and ultimately lead to poor plant growth.

This study addresses certain aspects of soil microbiological interactions with sewage sludge, the _in vitro_ response of VA mycorrhizal fungal spores to heavy metals, the effects of sludge on tree seedlings and their VA mycorrhizae under controlled environmental conditions, and the relationship between sludge and nitrogen-fixing leguminous trees with their symbiotic bacteria. This particular research area was initiated with the overall objective of determining the effects of sewage sludge on the development of vesicular-arbuscular mycorrhizae of forest tree seedlings. Studies were designed to determine 1) the effects of sludges from different sources applied at various rates on the development of VA mycorrhizae and growth of tree seedlings and 2) effects of sludges and heavy metal components on spore germination and hyphal development of VA mycorrhizal fungi.

SECTION 2

CONCLUSIONS

FIELD-GROWN CHRISTMAS TREES

Not all tree species respond similarly to all types of sludge or sludge loading rates. The waste treatment process itself influences tree growth indirectly by inducing different nutritional and/or toxicological properties in sludge. Sludge applications actually affect tree survival to a greater extent than growth. Poor survival associated with sludge is related to something other than ammonia alone because a tree mortality problem, when it occurs, can be observed beyond the first year.

The loading rate is generally more directly related to tree height growth on a poorly-drained soil than on a well-drained soil. On the other hand, a lime-ferric sludge caused growth differences in five conifers on a well-drained silt loam that were not seen on a clay soil.

Greater differences in the foliage element content of white pine are expected on the better drained soils. Other investigators have observed greater growth responses of tree seedlings treated with sludge than those reported herein. One reason for this is probably due to the present study being conducted on a previously tilled, well drained, silt loam soil that supported corn or wheat crops previously. The combination of tillage and residual fertility no doubt overshadowed some of the expected responses to sludge. Other studies have shown greater responses to sludge applications in forests of the West where native or initial fertility was at a much lower level prior to nutrient additions via sludge.

Both high weed densities and high sludge loading rates tend to decrease conifer seedling height growth. Weed density is directly related to sludge loading rates on both poorly-and well-drained soils.

ZANESVILLE STATE TREE NURSERY

In managed soil in the outdoor nursery, conifer seedlings generally respond to inorganic nitrogen amendments, but not to sludge. Among the several hardwoods studied, only black locust and yellow-poplar experience height growth stimulations due to applied sludge. The nursery soil was a coarse-textured, well drained, sandy loam, chosen as a seedling production soil partly because of its desirable drainage characteristics. As with field-grown Christmas trees, higher sludge application rates (greater than 35 MT/ha) cause reduced conifer shoot growth. Application rates in excess of 80 MT/ha result in intolerable weed growth unless the bed is fumigated after sludge application.

Sludges derived from different treatment processes can cause different element sorption patterns in trees. Sludges occasionally cause an increase in the tree absorption of phosphorus and a decrease in manganese. Other inconsistent conditions involve zinc and copper. Zinc levels in black locust and yellow-poplar should be higher when trees are grown in a primary treatment sediment (Detroit), but copper was higher in these same species grown in an anaerobically digested sludge (Mt. Vernon). One cannot generalize about sorbed metals based on the quantities in sludge since the high-chromium sludge from Mt. Vernon did not induce a higher amount in trees grown in it. In fact, by adding large amounts of cations as per sludge content and loading rate, large amounts of organic matter added concurrently tend to sequester many of these ions and render them inaccessible to trees. There appears to be some selectivity expressed among species relative to elements such as copper, magnesium, and calcium as sludge loading rates are not consistently related to element sorption by tree species.

Sludge loading rates greatly influence the rates at which water percolates through the soil-sludge medium.

CONTAINERIZED TREE PRODUCTION

For all conifer species tested, there are both stimulations in height and diameter growth associated with sludge in a peat-vermiculite medium. Trees grown in smaller containers are less likely to show responses to sludge than larger ones, probably because root growth is restricted by space constraints rather than nutrient availability. Noble fir does not respond to sludge in the growth medium as much as blue spruce, Douglas-fir, and white pine.

Winters in Ohio are generally prohibitive to the production of Noble fir in the field. Sludge in the medium seems to enhance better tree survival (98%) of outplanted Douglas-fir, white pine, and blue spruce than outplanted containerized seedlings grown in the absence of sludge (93%).

When sludge is incorporated in the rooting medium, tree growth is most associated with container (seedling) density rather than container volume or depth.

Sludge particle size and degree of stabilization also influences tree growth and survival. Coarse sludge, in general, produces heavier seedlings. Finely ground, activated sludge with chemical characteristics similar to those of Milorganite is distinctly phytotoxic. An addition of charcoal to the medium does not improve growth, suggesting that sorption of toxic materials alone is not the reason why seedling growth enhancement is associated with sludge.

Sludge appears to improve initial seedling development most. A bark-vermiculite medium severely limits seedling growth for about 2 months after germination due to bark toxicity and/or sequestering fertilizer elements (particularly nitrogen), but sludge amendments markedly reduce the severity of this effect.

MYCORRHIZAL RELATIONSHIPS

Although several tree species were not tested in this study, one can probably generalize somewhat from results involving sweetgum. Non-mycorrhizal seedlings respond much more to sludge than do mycorrhizal seedlings. The response difference is due primarily to phosphorus nutrition, and the difference in growth can be translated into a phosphorus stimulus equivalent of 50 ppm of added phosphorus. An activated sludge such as Milorganite can be expected to nearly eliminate a mycorrhizal response of soybeans via reducing the availability of phosphorus to the plants. Even after a second planting of soybeans in the same once-used soil-sludge mix one can expect a low recovery of mycorrhizal activity. In general, mycorrhizal infection will decline with increased sludge concentrations in a growth medium. Soluble heavy metals in sludge are generally detrimental to fungus spore germination and hyphal development. Soil concentrations of available or exchangeable zinc between 10 and 50 ug/g will cause an abrupt decline in Glomus macrocarpus chlamydospores. Lower levels of copper cause variable results, but amounts as small as 1 ug/g of exchangeable copper have detrimental effects on mycorrhizal fungus spore germination.

COPPER REQUIREMENTS OF CONIFERS

In many cases, and apparently for less-than-obvious reasons, tree response to sludge is greater than to various inorganic fertilizers. This indicates that the response in such instances is not due to major nutrients since treatments causing less growth of blue spruce and Douglas-fir induced higher foliar amounts of phosphorus, potassium, magnesium, and calcium. A close relationship exists between tree growth and copper availability in soils. Other metals do not seem to be as critical to growth. Copper availability is affected by the pH of sludge which is determined by the waste treatment process. For example, although the same total amount of copper might be added via a lime-ferric sludge, it is less available for plant uptake than when it is presented in an activated sludge with greater free acidity (lower pH). Copper deficiencies can be expected to be more severe in a bark-vermiculite medium than in a peat-vermiculite medium. In fact, mixing fairly large amounts of sludge with a bark medium will probably not supply sufficient copper even for white pine. Douglas-fir is the one conifer studied that not only responds well to a single, large copper application, but which can tolerate excessive copper loadings.

SECTION 3

RECOMMENDATIONS

FIELD-GROWN CHRISTMAS TREES

In previously tilled or fertilized soils, light sludge amendments (less than 45 MT/ha) can be applied as a disposal procedure which will insure tree survival, but substantial tree height growth differences will probably not be realized.

When sludge is applied to any soils (particularly fine-textured, poorly-drained soils) it is important to control competing weeds to insure the desired response of trees.

It is especially important to determine the nutritional status of any soil and sludge prior to sludge application as well as the drainage characteristics of the soil.

ZANESVILLE STATE TREE NURSERY

Any sludge applied to a nursery soil must be done and incorporated prior to soil fumigation to prevent intolerable weed competition.

Sludge application rates exceeding 80 MT/ha of primary treatment sediment (Detroit) are not recommended for conifers or hardwoods, and rates of anaerobically digested sludge (Mt. Vernon) in excess of 35 MT/ha are of little benefit to seedling production.

Desired water uptake rates by nursery soils should be considered prior to sludge incorporation because beneficial or adverse changes in soil-plant-water relationships are almost certain to occur for various sludge type/loading rate/soil characteristics combinations.

CONTAINERIZED TREE PRODUCTION

Sludge added at a rate of 3-4% (v/v) to a peat-vermiculite medium is suggested for improved growth of most conifers in containers and better survival when outplanted.

Containers with larger cavities are recommended for growing superior seedlings, but may present a problem in mechanical transplanters due to their size. Shipping costs of such trees are also substantial.

Because of potential phytoxicity and drainage problems, sludge should not be finely ground prior to incorporation into a growth medium.

MYCORRHIZAL RELATIONSHIPS

If mycorrhizal seedlings are desired for outplanting, one should exercise care in the selection and application of sludges because an overapplication can cause seedlings to be less than optimally infected by mycorrhizal fungi.

COPPER REQUIREMENTS OF CONIFERS

Adequate available copper must be present in the rooting medium because maximum growth of blue spruce and Douglas-fir occurs when foliage contains at least 2.3 ppm (w/w) copper.

A lime-ferric sludge is not recommended as a source of copper due to the copper being bound in high-pH sludge particles and not being available for plant uptake.

A bark-vermiculite medium is not recommended because it not only causes phytotoxicity, but sequesters fertilizer elements. Copper is essential for ideal seedling growth, but high loading rates of sludge containing abundant copper cannot provide sufficient quantities to meet seedling needs in a bark medium.

SECTION 4

EXPERIMENTAL PROCEDURES AND RESULTS

GENERAL PROCEDURES

Sample Digestion -- Plant tissues were dried at 70 C to a constant weight in a forced-air oven and ground in a Wiley mill. Two g or less were digested in a 5:2 solution of concentrated nitric/70% perchloric acid. Soils and sludges were digested using the same acids with sufficient hydrofluoric acid to dissolve any silicates present.

Analysis -- Sodium, potassium, and calcium were analyzed by atomic emission, and magnesium, iron, manganese, copper, zinc, chromium, and nickel were analyzed by atomic absorption spectroscopy. Sludge analyses were performed by the Research and Extension Analytical Laboratory (REAL) at the Ohio Agricultural Research and Development Center (OARDC) by inductively coupled plasma emission spectroscopy (ICP).

Extractions -- Phosphorus extractions from soils were done using 0.5 M Na HCO_3 (Olsen) or 0.03 N NH_4 F and 0.025 N HCl (Bray #1) (Olsen and Dean, 1965). Ammonium and nitrites were extracted with 1.ON KCl (1:4 soil to solution and shaken for 1 hr.) (Bremner, 1965). Three 25-g samples of moist soil from four replicated pots were used for simultaneous pH and dry weight determinations and extractions. Extracts were filtered and analyzed with an Orion ammonia ion specific electrode (Siegel, 1980) and by the modified Griess - Flosvay nitrite method (Bremner, 1965).

Organic Matter -- Organic matter was determined at the Research and Extension Laboratory by the Walkley-Black (chromic acid digestion) method.

Water Content -- Soil moisture content was determined by dividing the weight of the water lost at 70C by the dry weight of the sample at 70C.

pH -- Free, unbuffered soil acidity (pH) was determined using a Sargent-Welch meter and a glass combination electrode. Soil pH's were determined in a 1:1 soil/water system.

Statistical Analyses -- Data were analyzed by analysis of variance with subsequent mean separations by Duncan's Modified LSD Test. The computer program, MINITAB (Ryan et al.) was used for one and two-way analyses of variance and for determining correlations and regressions. Factorial analysis was done with a Statistical-Program-for-the-Social-Sciences (SPSS) program.

SLUDGE AMENDMENTS

Several things are done to solids in a waste treatment facility. Among these are stabilization, dewatering, and eventual disposal. The purposes of these procedures are to stabilize the solids so that when disposed of they will not become a nuisance and to reduce the ultimate amount of solids to be discarded.

Stabilization procedures include digestion, composting, chemicals, and heat treatment. Sludges used in the various studies reported in this paper are representative of several different stabilization techniques. Primary sludge, such as from Detroit, is raw sludge obtained in the primary stage of the treatment plant by collecting solids, both settled out and floating. Activated sludge, as from Milwaukee, is obtained in the secondary stage of treatment by settling flocculated bacteria cells that have been feeding on the soluble and suspended organic material in the sewage. Primary and activated sludges can be further treated to obtain a stabilized sludge in which the organic matter has been decomposed into a fairly stable material.

Aerobic and anaerobic digestions are common methods of stabilizing solids which produce a digested sludge. Anaerobically digested sludges used in these studies were obtained in Wooster and Mt. Vernon, Ohio. A major reason for increased emphasis on anaerobic digestion, lime treatment, and composting is the increased emphasis placed on sludge use instead of mere disposal. In anaerobic digestion, acid-forming bacteria transform the organic substrate into volatile organic acids, and although the pH drops somewhat, the total amount of organic material in the system does not change much. This entire process is controlled primarily by methane (CH_4)-producing bacteria. The second stage of anaerobic digestion involves the conversion of the organic acids to CH_4 and CO_2. Even though there can be phytotoxicity from nitrates, this type of sludge appears desirable for crop fertilization. Primary and undried waste-activated sludges have use limitations caused by odor and house fly attraction when landspreading is considered. Additionally, the cost of applying dried waste-activated sludge in quantities great enough to provide sufficient nutrients for most crops makes its use somewhat unattractive.

Lime-treated sludges from Cleveland Southerly and Lakewood, Ohio were used in the study. In a lime treatment there is no destruction of organic matter. In this regard, the organic matter content (15%) of the Lakewood sludge is quite low, much lower than one would expect. However, the low organic matter content of the greenhouse mix is due to proportionally more of the weight being associated with additives other than sludge. A waste pH of near 11.0 is maintained by lime addition to insure the destruction of human pathogens and sludge stabilization. Because of the high alkalinity, many cations normally available in sludge stabilized by other methods are bound and rendered relatively unavailable in lime-treated sludge.

Sludges used in these studies are described on Table 36. Application rates and mixing procedures are described for each study. The sludges used ranged from 4.2% solids for the liquid Lakewood lime-ferric sludge to nearly 50% for the heat-stabilized Zimpro sludge from Canton, Ohio. Sludge cakes from North Olmsted, Ohio and Detroit, Michigan contained 33.9% and 31.2% solids, respectively. No attempts were made to identify and quantify volatile organics in any of the sludges.

The combination and interaction of waste components, stabilization technique, and dewatering procedure not only determine the consistency of a sludge, but influence the chemical nature of the sludge. The ultimate availability of plant nutrients and toxicants in the soil solution where sludge has been applied as a fertilizer is determined by both sludge quality and physical and chemical characteristics of the soil.

FIELD-GROWN CHRISTMAS TREES

Procedures

Two Christmas tree plantations were established near Wooster, Ohio, one on a good site with well-drained Wooster or moderately well-drained Canfield silt loams previously cropped to corn or hay (Secrest Road site), and one on a poorly-drained Ravenna silt loam recently cleared of large hardwood trees (Dunham Farm site). Characteristics of soils prior to treatment are indicated in Table 37. A comparison between before-and after-treatment soil conditions indicates substantial increases in certain nutrient elements (Ca) and little change in others (Mg) (Table 37, Table 38). The exchange capacity, calcium levels, and organic matter content only changed significantly following sludge additions of 90 and 180 MT/ha of Cleveland sludge. Alkalinity generally increased with the additions of more sludge on the plots. The amount of sludge added made no difference relative to the amounts of potassium and magnesium detected in soils, and there seemed to be little relationship of soil phosphorus content to the amount of sludge applied. During the winter and spring of 1980, 12 x 15 m plots replicated four times, were treated with 0, 11, 22, 45, 90, or 180 MT/ha (dry weight basis) of Cleveland (Southerly Treatment Plant) sludge (Table 36). These plots were rotovated and transplanted with twenty seedlings or transplants each of 2-2 Colorado blue spruce, 2-2 Douglas-fir, 4-1 fraser fir, 3-0 Scots pine (Spanish Guadarrama), and 2-0 eastern white pine. Trees failing to survive the first winter at the Secrest site were replaced with extra trees of the same lots that had been heeled in. The Dunham Farm site was replanted in 1981 with 16 replicates per plot of 2-0 white pine and with trees of the other four species obtained from the same nursery lots as before, but now a year older, e.g. 2-3 blue spruce, etc. In 1981, additional plots at the Secrest site were treated with 0, 11, 22, 45, and 90 MT rates of sludge from the North Olmsted, Ohio treatment plant. These plots were rotovated and planted with the same lots of trees used in the second Dunham Farm planting. In addition, 16 1-0 yellow-poplar and 12 additional 2-0 white pine seedlings were interplanted into each of the 44 Secrest site plots.

New terminal growth of all trees was measured in the summers of 1980 and 1981. Total height of all conifers was measured in 1982. In 1980, white pine needles from one branch of each seedling were combined for each plot and analyzed for various chemical elements. In 1981, the interplanted white pines at the Secrest site were harvested in total and: 1) roots were rated for fine root and mycorrhizal development, 2) roots and shoots were dried and weighed, and 3) needles were analyzed for various elements. In the summer of 1980, four 0.5 m^2 subplots/plot were clipped by hand prior to any mowing and weed biomass was determined. Weeds were separated and classed by botanical family to determine if sludge application increased weed growth or if it altered weed species composition. Soil analyses were performed for the Secrest site in July, 1980 after application of the Cleveland sludge.

Results

At the Secrest plantation in Wooster, Ohio, sludge at various rates slightly improved the growth of all species but Fraser fir (Tables 1 and 2). With the lime-ferric (Cleveland) sludge, growth was greatest at the 11 or 22 ton rates, with marked growth reductions at higher rates. In contrast, maximum growth in the Zimpro (North Olmsted) sludge-treated plots occurred at the two highest rates, 45 or 90 MT/ha. At the Dunham plantation (which was less fertile, acidic, and often wet), best growth of seedlings planted soon after sludge application occurred in the non-treated control plots (Table 3). Growth of seedlings planted a year following sludge application was less affected by low rates of sludge, but as with the first planting, differences were usually not statistically significant. At the Secrest site, maximum survival in the lime-ferric sludge occurred at the 11 and 22 ton rates (significant only for white pine). At these rates, average survival for the combined five species was 65% and 69%, respectively, versus 56% for the control. In Zimpro sludge-treated plots, no consistent effect was detected, partly because of the inclusion of several wet plots with abnormally low survival rates. At the Dunham plantation, survival was inversely proportional to sludge rate in both the 1980 and 1981 plantings (Table 3). Furthermore, the approximate degree of toxicity was the same in both years, as indicated by the similarity of the slopes for regression of survival on sludge rate. Regression equations of sludge increments (1-6=0-180 MT) on survival in 1981 and 1982 are 74-5.40 X and 70-5.97 X, respectively. This indicates that the deleterious effect of sludge on survival was not transitory (for example, because of high initial ammonia accumulation), but persisted for a year at about the same intensity.

The survival of blue spruce, Douglas-fir, Fraser fir, and the pines was influenced by sludge loading rate. At rates in excess of 45 MT/ha, survival was significantly poorer after 2 years in the field than survival at lower loading rates. Although there were significant differences in growth among various tree species at different loading rates, there seems to be no distinct trend as to which sludge loading rates were either the best or the poorest for tree growth. The only consistent relationship appeared to be the growth of Scotch pine in 1981, or after 2 years in the sludge (Table 1). The sludge loading rate of North Olmsted (Zimpro) sludge in 1981 appeared to have no effect at all on the growth of blue spruce, Douglas-fir, Fraser fir, Scotch pine, and white pine in the same year of sludge application. After 2 years in the field, sludge apparently had no effect on the eventual total height of these same species at the end of the growing season in 1982. But survival of these same species was generally better at the lower sludge loading rates. Sludge loading rate appeared to have little effect on the survival of either Scotch pine or white pine (Table 2), however. Cleveland sludge applied at the Dunham site caused few apparent differences in growth in 1981 among all sludge loading rates and all species tested. This same combination of poorly-drained soil and Cleveland sludge also had very little effect on the total height of trees at the end of the 1982 growing season. But the survival at the end of two growing seasons was significantly better in general for sludge rates less than 45 MT/ha (Table 3).

Although there were differences in the average conifer height resulting from sludge loading rate and the correlations between loading rate and height were extremely strong, the correlation between sludge loading rate and weed density was not significant (Table 4). At the Dunham site only 22.4% of the variation in weed density was associated with loading rate while 98.6% of the variation in total height was associated with loading rate on this poorly-drained soil. Eighty-one percent of the variation in height was associated with variation in loading rate on the best-drained soil at the Secrest site. More importantly, less than 2% of the variation in weed density was associated with height growth at the Secrest site, and approximately 20% of the variation in weed density was associated with variation in height growth on the poorly-drained soil at the Dunham site. Greater weed densities tend to decrease height growth, and the higher sludge loading rates also tended to decrease height growth. When considering only the lowest five loading rates, loading rate was directly correlated (r^2=85%) with weed density at both the Secrest and Dunham sites.

North Olmsted sludge applied in 1980 had no significant effect on the height-growth of interplanted yellow-poplars at any of the sludge loading rates tested in 1981, and there appeared to be no differences in survival of yellow-poplar in these various treatments. However, there were differences in total height growth among the various sludge loading rates, and at rates exceeding 22 MT/ha the survival percentage of yellow-poplar trees decreased, particularly in the North Olmsted sludge (Table 5).

Growth of interplanted white pine seedlings in Cleveland sludge at both the Secrest and Dunham sites differed with greater growth of pine seedlings occurring at the Secrest site where the same sludge loading rates were applied than on the heavier, more poorly-drained soil at the Dunham site (Table 6). There were slight differences in the amount of magnesium present in pine foliage produced at the Secrest site, but more pronounced differences in magnesium content of foliage of trees grown on the heavy soil at the Dunham site. However, there were no significant differences in the amount of foliage calcium at the Secrest site and only slight differences at the Dunham site (Table 6). Although there were no differences in the potassium contents of foliage from trees grown at either site, there were significant differences in the amount of phosphorus present in foliage on trees at the Secrest, but not at the Dunham site. In general, greater differences in foliage element content were observed at the Secrest site. Where sodium varied somewhat in foliage according to sludge loading rate at the Secrest site, no such difference was observed at the Dunham site. Elements such as chromium, copper, and zinc were not different in concentration in foliage from trees grown at either site or among the loading rates.

There appeared to be no significant differences in the amounts of foliage calcium, iron, manganese, and zinc in white pines grown at the Secrest site in both the North Olmsted and Cleveland sludges. There were however, some differences in copper, phosphorus, potassium, and magnesium levels in trees grown in the Cleveland sludge (Table 7).

There were no differences in the shoot weights of white pines grown in either North Olmsted or Cleveland sludge at any of the loading rates tested, and there were only slight differences in root weights of trees grown on the North Olmsted sludge. There were no differences in the shoot-to-root ratios for any trees grown on either sludge type at any sludge loading rate. There was, however, a slight difference among loading rates relative to mycorrhizal incidence in white pine grown on the Cleveland sludge and more pronounced differences among those grown on North Olmsted sludge. Mycorrhizal infection appeared to be hindered at sludge loading rates from both sources in excess of 45 MT/ha.

ZANESVILLE STATE TREE NURSERY

Procedures

Eight adjoining 1.2 x 90 m beds of a sandy loam soil were plowed, disked, and fumigated with methyl bromide/chloropicrin in September 1979. In October, a poorly digested (primary treatment only) municipal sludge from Detroit, Michigan and an anaerobically digested liquid sludge (ca. 10% solids) from Mt. Vernon, Ohio (Table 36) were applied with a manure spreader at approximate rates of 35, 80, and 200 MT/ha (dry weight basis). Storage on and removal of sludge from the ground prior to spreading resulted in some sludge contamination with unfumigated soil. A seventh plot was left untreated as a control, and the eighth plot was fertilized with 120 kg/ha of $NH_4 NO_3$ in the spring of each year. Ammonium nitrate at this rate is normally applied for seedling production at this nursery, but applied only once and prior to seeding.

A partial nutrient characterization of nursery soils prior to (Table 37) and after treatment (Table 39) is presented. By the addition of Detroit or Mt. Vernon sludge, the most noticeable differences in the characteristics of nursery soils are those of slightly elevated pH and CEC accompanied by increased amounts of phosphorus, calcium, and magnesium.

In the spring of 1980, the eight beds were disked and seeded with northern red oaks (*Quercus rubra* Du Roi), black locust (*Robinia pseudoacacia* L.), yellow-poplar (*Liriodedron tulipifera* L.), Douglas-fir (*Pseudotsuga menziesii* (Poir) Britt.), Noble fir (*Abies procera* Rehd.), Colorado blue spruce (*Picea punguns* Engelm.), Scots pine (*Pinus sylvestris* L.), eastern white pine (*Pinus strobus* L.), and Virginia pine (*Pinus virginiana* Mill.). These species were planted in 1.2 x 1.2 m plots replicated five times at random in each 90 m bed. Weeds developing either from tomato seeds surviving sewage treatment, from sod or seeds in the soil inadvertently spread with the sludge, or from seeds occurring naturally in the beds were removed by hand in all but the highest-rate treatments of both sludges. These were abandoned. In late July, approximately 20 plants were harvested from each plot. Root and shoot weights were determined, and foliar chemical analyses were performed on yellow-poplar shoots and black locust leaves.

In September 1980 the site was again disked and fumigated to destroy weed seeds. Following fumigation, the beds (previously amended with sludge) were disked, divided into 10 blocks of 11 0.6 x 1.2 m plots and seeded with white oak (*Quercus alba* L.), red maple (*Acer rubrum* L.), black locust, sycamore (*Platanus occidentalis* L.) Scots pine, Virginia pine, eastern white pine, Douglas-fir, noble fir, and blue spruce. The seeds were placed in furrows, covered with sawdust and hydromulched. In 1981, the faster growing species (white oak, sycamore, yellow-poplar and black locust) were harvested, weighed, digested, and analyzed. During the summer of 1982, the red maples and Virginia pines were also harvested, weighed, and analyzed. The other conifer species were not harvested because of generally poor or inconsistent survival and development not associated with specific sludge treatments. In some cases, the 35 MT Mt. Vernon treatment was not harvested because of heavy weed development, possibly from seeds introduced with the sawdust or hydromulch. The 80 MT Detroit treatment was not reported in some cases because several plots were periodically flooded, and growth was either poor or was not initiated. Water content, water intake rate, aggregate stability, and organic matter content were determined for the beds in the summer of 1982, about 33 months after they had been treated with sludge.

Results

In the summer following fall application of the Detroit and Mt. Vernon sludges at the Zanesville Nursery, certain sludge rates significantly improved the growth of black locust and yellow-poplar seedlings (Table 9) relative to the control receiving no nitrogen. Red oak was not affected, possibly because its large seed nutrient reserves diminished the effects of soil nutrients on initial development. Coniferous seedlings as a group responded significantly to inorganic N, but not to sludge. The 80 MT/ha rate of Mt. Vernon sludge reduced conifer shoot growth significantly, and in some cases, a poorer root system was evident. The two 200 MT rate treatments were abandoned because of the heavy growth of weeds derived either from soil mixed with the sludge, seeds in the sludge (mostly tomato), or naturally occurring seeds. This underscores the need to apply sludge prior to soil fumigation to eliminate germination of sludge-borne seeds which develop into particularly dense weed growth due to excessive available soil nitrogen.

Sludge treatments increased uptake of phosphorus in some cases, and generally decreased Mn uptake (Table 10). Foliar Zn was higher with the Detroit sludge treatments, and Cu was higher in certain treatments, particularly those with Mt. Vernon sludge. However, foliar Cr was not significantly higher in trees of plots treated with the high-Cr Mt. Vernon sludge.

Following refumigation and seeding, growth of black locust and white oak was generally not affected by sludge (Table 11). Some of the sludge treatments, although they included significant amounts of various nutrient elements, did not result in increased uptake and detection of these particular elements in the foliage of the species studied. In fact, by the addition of large quantities of organic matter by way of sludge, it appears that some of the cations present in the mix were also sequestered by the concurrent organic matter amendment. On the other hand, elements such as copper were accumulated at higher concentrations in certain species such as sycamore, yellow-poplar, black locust, and red maple. Small, if any, differences were detected for this element relative to sludge loading rates re Virginia pine and white oak. Sludge loading rate was not consistently correlated with increased uptake of various elements over all species. There appeared to be some selectivity expressed among species relative to certain elements such as copper, magnesium, and calcium. In the second seeding, the higher soil levels of P from the Mt. Vernon sludge treatments were reflected in foliar analyses of some of the species, and Mn, Cu, and Zn patterns were similar to those of the first year. Foliar magnesium was again lower in a few treatments.

Soil organic matter and water contents were significantly increased only by the addition of the highest rate of Detroit sludge (Table 12), the same treatment that improved the growth of several tree species. Water intake rate varied widely, but showed no consistent relationship to sludge loading rate. Mean soil particle diameters varied slightly, but were not significantly affected by sludge treatments in this soil. Although the mean geometric diameters of the soil aggregates were not significantly different among all sludge treatments over the two types of sludge at the Zanesville nursery, there were some slight differences in the organic matter present.

The moisture content between samplings in 1982 (June and July) indicated that there was slightly more moisture at the later sampling, but the differences in water content of the soil plus sludge were not as great as those observed during the June sampling period (Table 12). There were substantial differences in the rates at which water was taken up or absorbed by the various sludge treatments. Water penetrated the soil mix anywhere between 0.27 and 0.93 cm per minute. These rates were correlated neither with the water content of the soil nor with the organic matter present.

CONTAINERIZED TREE SEEDLING PRODUCTION

Procedures

The containers used are listed in Table 40. The rooting medium used was 1:1 ratio of peat (Premier, Riviere du Loup, Quebec) and #2 horticultural vermiculite adjusted to an initial pH of 5.5 with 1 g of hydrated dolomitic lime per liter of mix. Granules (2-9 mm) of dried anaerobically digested sewage sludge (GH-An, Table 36) were added at 4% and 3.5% (v/v) in 1980 and 1981, respectively.

In 1980, containers of each type listed in Table 14 were replicated five times (one replicate per bench). One fourth of each container unit was seeded with either white pine, blue spruce, Douglas-fir, or noble fir and covered with a 1 cm layer of vermiculite. The same procedure was followed in 1981 for the container types listed in Table 15. Extra replicates of the paper or tarpaper bands were included to increase the numbers of individual seedlings. Seedlings were thinned to one per cavity after the seed coats were cast.

In 1980, the rooting medium in container cavities in the 0.16 - 0.17, 0.33 - 0.37, and 0.66 - 0.74 l volume groups was fertilized twice weekly with 10, 20, and 40 ml, respectively, of a solution containing 150 ppm N (7:3 NO_3^- to NH_4^+ ratio), 50 ppm P, 100 ppm K, 65 ppm Ca, 40 ppm Mg, 50 ppm S, 5 ppm Fe, 0.5 ppm Mn, 0.5 ppm B, 0.05 ppm Zn, and 0.01 ppm Mo (pH 5.7). In 1981, the medium was fertilized once weekly with half the volume of the above solution at 2.4 times the previous strength. An equivalent amount was sprayed over the tree foliage once weekly. Sulfuric acid was added in 1981 to neutralize water alkalinity. Each 5 x 8 ft. bench was illuminated by two metal halide lamps that provided an average supplemental light intensity of 400 lux at the tops of the containers for 24 hours per day in 1980 and 18 hours in 1981. Containers were seeded in early June. At the end of December, 1980 and again in mid-December, 1981, the greenhouse temperature was lowered over 2 weeks to allow an ambient night temperature of 2-5 C.

In the first year, the best 30 trees from each treatment were identified, and root crown diameters and shoot heights were measured. Of these, 20 were outplanted in five, completely-randomized blocks with trees spaced 0.6 m within rows and rows separated by 1.2 m. Ten were dried at 70 C for root and shoot weight measurements. In the second year, all seedlings were measured prior to planting and the best twenty-five were outplanted. Planting was done by hand at a spacing of 0.6 m in 5 completely randomized blocks of five trees. Trees in all plantings were measured at the end of their growing seasons.

Sludges as Fertilizer Supplements -- In two subsequent experiments the peat-vermiculite medium was amended with the treatments listed in Tables 18 and 19. Five replicates of each treatment in the first experiment were seeded with eight seedlings each of Douglas-fir and blue spruce in 0.35 l book containers. The second experiment was seeded only with blue spruce and was also replicated five times with eight seedlings/replicate. Both experiments were maintained for 3 months, and seedlings were fertilized as previously mentioned for the 1982 container trial. At the end of the 11-treatment experiment, the blue spruce and Douglas-fir seedlings were measured, harvested, weighed, digested, and analyzed for various elements by procedures mentioned previously. Seedlings in the 24-treatment experiment were measured and weighed.

Sludge Amendments -- Partially digested sewage sludges were obtained from Canton (Can), Cleveland (Cle), and Mt. Vernon (MV), Ohio, and Detroit (Det), Michigan. The pH, organic matter content, and mineral composition of each sludge is given in Table 36. Sludges were air-dried and small volumes were ground dry in a Waring blender. Ground sludges were screened through sieves to obtain particles 1 - 3 mm diameter, 3-5 mm diameter, and 5-7 mm diameter. Equal volumes of particles within each size range were mixed together.

A potting mixture of two parts soil, two parts sand, and one part peat moss was prepared. The powdered sludges were added to the soil mix to achieve concentrations of 2.5%, 5%, 10% and 25% sludge, on a volume-volume basis. Five hundred seventy-five ml of potting mix were added to each 600 ml styrofoam container.

Results

The effect of a sewage sludge supplement on the average growth of tree crops of greenhouse-grown containerized seedlings is shown in Table 13, with detailed breakdowns by year and container type in Tables 14 and 15. Responses to sludge were statistically significant in every growth category for every species. In comparisons of individual container types for 1980, the smaller sizes were less likely to show significant responses associated with sludge than the larger sizes. This may have occurred because growth was more restricted by space limitations than by nutrition. In the 1981 trials, noble fir was the species least likely to respond to sludge, and it accounted for most of the treatments not resulting in a significant sludge response. Differences in growth of the 1980 seedlings persisted after transplanting, with an average survival rate of Douglas-fir, blue spruce, and white pine seedlings of 98% for trees grown in sludge versus 93% for those without sludge. Winter mortality of noble fir was too great to justify measurements in 1982. Within the treatments receiving sludge, the effects of different container types on growth were substantial and were most associated with container (seedling) density rather than container volume or depth (Table 16).

In the study involving soil treatment with either 1 or 5% (v/v) sludge from four sources to add nitrogen to the growth medium for Douglas-fir, there were significant differences in tree survival (Table 24). The greatest survival was observed in treatments involving either no sludge application or North Olmsted sludge (Zimpro) added at 1% by volume. The only treatment where great reductions in survival were observed were in both the activated sludge treatments using Milwaukee sludge and the lime-ferric treated sludge from Lakewood, Ohio. Survival in the latter treatments ranged from 9 to 60%. Anaerobically digested sludge as well as that treated by the Zimpro process provided survival percentages between 82 and 93%. These did not differ significantly from the control treatment.

MYCORRHIZAL RELATIONSHIPS

Procedures

Mycorrhizal and Rhizobial Inocula -- Chlamydospores of *Glomus fasciculatus* were obtained from pot cultures of corn by the process of wet-sieving and decanting (Gerdemann & Nicolson, 1963). Two hundred fifty spores were mixed with the soil in each pot. The *Rhizobium* isolate used in this experiment was obtained from nodules collected from black locust (*Robinia pseudoacacia*) roots from Franklin County, Ohio. Fifteen black locust root nodules were surface-sterilized for 2 minutes in 10% Clorox and rinsed twice in sterile distilled water. The nodules were placed in a Waring blender with 600 ml sterile, distilled water and ground for 20 seconds. Five ml of the resulting suspension (4 X 10^7 Rhizobium cells/ml) were pipetted onto the soil surface of each pot.

Planting and Environmental Conditions -- Seeds of black locust (Robinia pseudoacacia L.) were immersed in concentrated H_2SO_4 for 70 minutes, rinsed in sterile distilled water, and planted at the rate of 20 seeds per pot. Following germination the seedlings were thinned to two per pot.

Pots were arranged in a controlled environmental chamber in a completely randomized design. Fluorescent and incandescent lights were used to provide a 14-hour day length with a light intensity at the center of the chamber of 940 microeinsteins/m^2/sec (400 - 700 nm wave length range). Day and night temperature controls were set at 25 C and 19 C, respectively. Pots were watered two to four times weekly.

Assessment of Plant Growth, Nodulation and Mycorrhizal Development -- After 10 weeks the height of each seedling was measured. Stems were cut at the soil line, and tops were dried for 24 hours at 70 C and weighed. Root systems were carefully washed free of soil and nodulation was assessed by the rating system of Corbin et al., (1978). Roots were then cleared in a solution of 10% KOH, and fungal structures were stained with 0.05% trypan blue in a lactic acid-glycerine-water solution (2:2:1, v:v:v). The percent mycorrhizal root length was estimated visually at 40 - 80X and rated according to the Horsfall-Barratt (1945) rating method.

Spore Germination -- Spore germination of G. fasciculatus chlamydospores was assessed using the method of Hepper (1979). The potting mixture was amended with sludges at the concentrations previously described. Approximately 60 spores of G. fasciculatus were placed between two millipore membranes which were cut to fit a photographic slide binder. Six slide binders containing spores were placed in a vertical position in the soil in each cup and covered with approximately 3 cm of soil. Pots were returned to the same environmental conditions as previously indicated although no seeds were planted in any pot. Each pot received 100 ml deionized -distilled water two times during the 10-day incubation period. After 10 days pots were removed from the growth chamber with the spores in slide binders still in place and stored at 4 C until processed. Individual slide binders were removed from soil, and the adherent soil was carefully removed by rinsing. Binders were opened and 1-2 drops of 0.05% aqueous cotton blue was applied to the inner surfaces of millipore filters containing spores. This stain had been found in previous tests to provide excellent visibility of germ tubes on the millipore membrane. Determinations of spore germination were made at 100 - 400 X.

In the study to determine heavy metal effects on germination and hyphal development, an isolate of Glomus macrocarpus Tul. and Tul. var. macrocarpus Gerd. and Trappe was used throughout. Spores were extracted from pot cultures of corn by a combination of wet-sieving and decanting (Gerdemann and Nicolson, 1963) and a modification of sucrose centrifugation as described by Ohms (1957). Sievings in the 90 - 149 um fraction were washed with water into 15 ml conical tubes and centrifuged at 1000 G for 3 min. Water was decanted and the spore and debris pellet was resuspended in a solution of 454 g sucrose per liter of distilled water. The spore suspension was centrifuged for 3 min at 1000 G and the supernatant was decanted through a 74 µm sieve. The sieve retained spores of G. macrocarpus, which were almost completely free of debris. Spores were rinsed 1 - 2 min with running distilled water to remove sucrose and then placed in 0.5% NaClO for 90 sec for spore surface disinfestation. Spores were rinsed through two changes of sterile, distilled water and aseptically transferred to metal- or sludge-amended agar.

Heavy-metal amended agar was prepared using Difco Bacto agar. This agar had been shown previously to be among those suitable for spore germination experiments (Hepper and Smith, 1976; Daniels and Graham, 1976). The sulfate salts of manganese (Mn^{++}), nickel (Ni^{++}), copper (Cu^{++}), and zinc (Zn^{++}) were incorporated into 1.5% agar prior to autoclaving. Sludge-amended agar was prepared using sewage sludge from Mt. Vernon, Ohio. The composition of this sludge is given in Table 36. Sludge was air-dried, ground to particle sizes less than 840 µm, and incorporated into 1.5% water agar prior to autoclaving. A no-sludge control was also included. In one experiment, sludge was incinerated prior to incorporation into the medium. This was accomplished by burning the ground sludge with a Bunsen burner flame until a constant ash weight was obtained.

A minimum of 50 spores in 0.3 ml water was pipetted onto the metal- or sludge-amended agar in each Petri plate. There were four to 10 replicate plates for each experiment. Plates were incubated in the dark at 21 C for 21 days. After this time, germination and hyphal development of individual spores was assessed for each treatment, or plates were stored at 2 C to prevent further germination or germ tube growth until observations could be made.

Mycorrhizal Colonization -- Root samples were fixed in 70:20:5:5 solution of ethanol: water: acetic acid: 37% formaldehyde (FAA) for at least 1 day. These were rinsed, boiled in 10% KOH solution, rinsed again and stained with trypan blue in lacto-phenol (Phillips and Hayman, 1970). Root pieces were mounted on slides and colonization was calculated as the percentage of 3 mm long root sections containing any mycorrhizal fungus structures.

The effect of various rates of soil amendment with sewage sludges from four municipal sources on the development of VA mycorrhizae, nodulation and growth of black locust was assessed in a growth chamber experiment.

Results

A growth chamber study of the mycorrhizal relationships involving black locust grown in a sludge-amended soil mixture in containers showed a significant interaction of sludge source and concentration on seedling growth. With three of the sludges tested, growth of seedlings was stimulated at low concentrations of sludge (10% or less) and greatly reduced at the high concentration (25%). Even a 10% sludge concentration is high compared to field application rates. With one sludge, low rates of addition to the soil mix suppressed growth, while the high rate greatly enhanced growth. In general, mycorrhizal development was decreased with increasing concentrations of sludge, and this decrease was apparently not related to spore germination *per se*, which was not affected by sludge in any treatment combination. Excellent growth of seedlings was achieved in the absence of VA mycorrhizal development. Growth of seedlings was highly correlated with nodulation.

In a second series of experiments, *in-vitro* germination and hyphal development of *Glomus macrocarpus* var. *macrocarpus* was reduced by addition of sludge to an agar medium. Addition of sulfate salts of manganese, zinc, copper, and nickel to an agar medium also reduced growth and hyphal development of *G. macrocarpus*.

Results of these studies indicate that effects of sludge on tree seedling growth can be highly variable depending on sludge source and concentration. Whether or not sludge-induced suppression of mycorrhizal development is related to heavy metal toxicity to mycorrhizal fungi should be determined.

Seedling Growth -- Growth response as a function of sludge amendment was similar for Can, Clev, and Det sludge sources (Figures 1 & 2). In Can and Clev sludge treatments, low concentrations (2.5, 5%) of sludge in the potting mixture stimulated plant growth, as indicated by height and dry weight measurements. In the Det sludge treatment, 10% sludge gave the greatest height and dry weight increases over the controls. However, 25% sludge concentrations caused a dramatic reduction of plant growth with all three sludge sources. These responses indicate a fertilizer effect at low sludge concentrations, but phytotoxicity at the 25% sludge rate. Most plants grown at the 25% sludge rate in these three sludge sources were severely stunted, chlorotic, and had few leaves (Figure 3).

Seedling growth response in the Mt. Vernon sludge treatment differed considerably from that previously described for Can, Clev, and Det sludges. Low rates of MV sludge (2.5, 5, & 10%) depressed seedling growth; however, seedlings grown in the potting mixture with 25% MV sludge showed a substantial increase in growth, as compared to no-sludge controls (Figures 1 & 2). Seedlings in the 25% MV sludge treatment were more vigorous than plants in any other treatment (Figure 3). Although these results suggest a substantial fertilizer effect at the 25% MV sludge rate, tissue mineral analysis showed no increases in concentrations of any nutrient in the 25% MV sludge treatment as compared to no-sludge controls (Table 32). However, N content of seedlings was not measured, and it is possible that N was chiefly responsible for the enhanced growth resulting from this sludge treatment.

The apparent growth reductions occurring at 2.5, 5 & 10% MV sludge rates may have resulted from the introduction of a weak pathogen with the sludge amendment. Closer examination of stunted seedlings in these treatments revealed numerous reddish-brown lesions in the area of the root crown. *Fusarium* and *Rhizoctonia* species were isolated from these lesions. Since sludges were not sterilized prior to addition to the potting

FIGURE 1

Figure 1. Effect of varying concentrations of sludge from four municipal sources on shoot dry weight of black locust seedlings 10 weeks after seeding

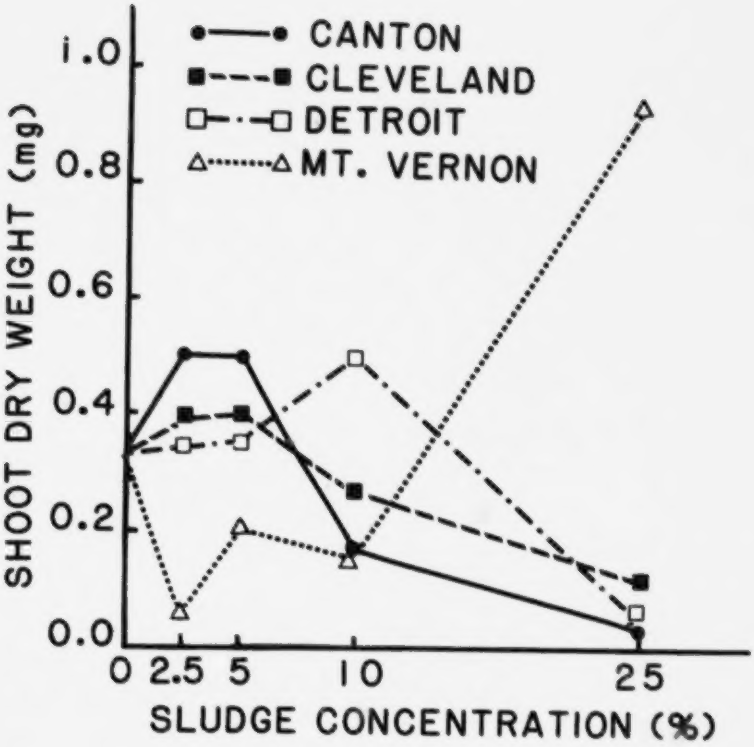


FIGURE 2

Figure 2. Effect of varying concentrations of sludge from four municipal sources on height of black locust seedlings 10 weeks after seeding

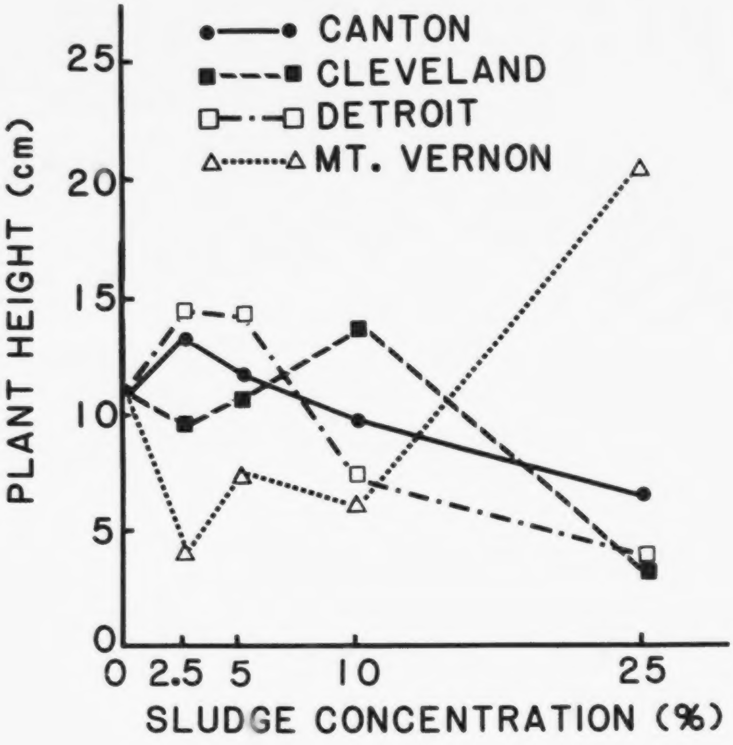
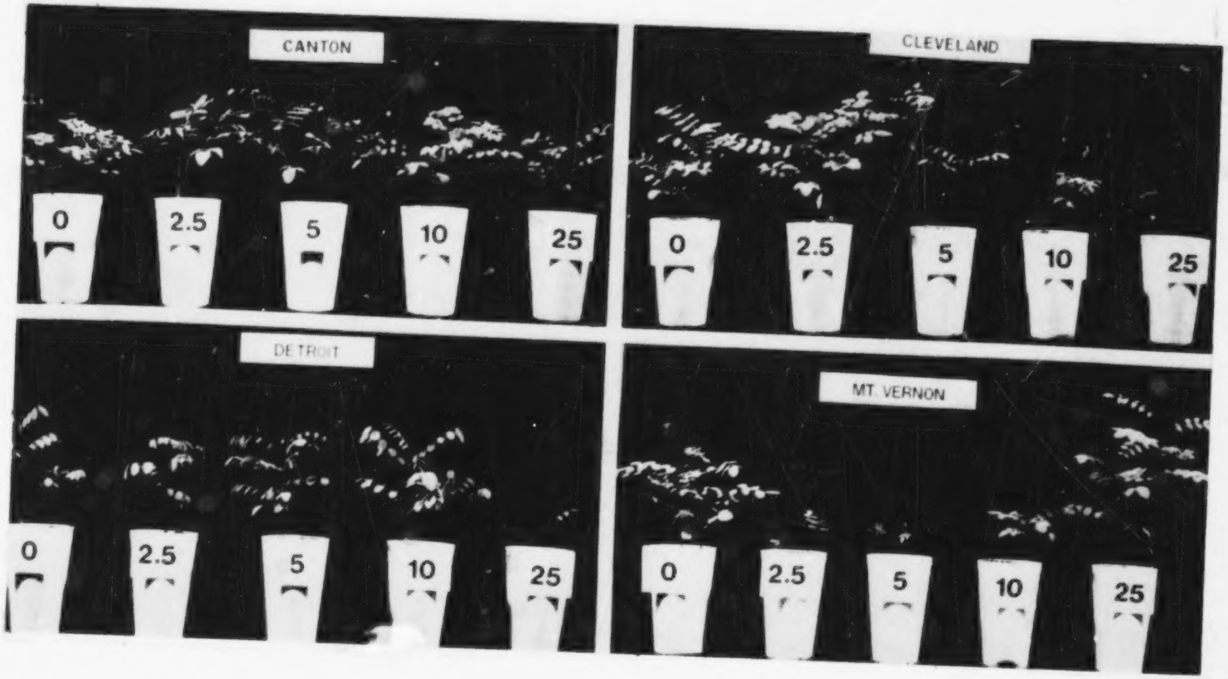


FIGURE 3

Figure 3. Representative black locust tree seedlings grown at various concentrations (percent by wt.) of municipal sewage sludge from four sources


CANTON
0
2.5
5
10
25
CLEVELAND
0
2.5
5
10
25
DETROIT
0
2.5
5
10
25
MT. VERNON
0
2.5
5
10
25

mixture, it is possible that a pathogen was carried with the sludge, and thus growth reductions at low rates of MV sludge resulted from fungal infection rather than from toxic components of the sludge. Infections may have been reduced or eliminated at the 25% sludge rate as a result of increased seedling vigor from added nutrients, or as a result of direct toxicity of sludge components to the causal organism.

Mycorrhizal and Rhizobial Development -- In general, mycorrhizal infection declined with increasing concentrations of sludge in the potting mixture (Figure 4). This was true for all sludge sources. Seedlings from the 0 sludge treatments had mean mycorrhizal infection ratings of 4.7 - 6.0, or approximately 25 - 50% infected root length. However, seedlings in the Clev, Det, and MV 25% sludge treatments had no mycorrhizal infection, and seedlings in the Can 25% sludge treatment had only a trace of mycorrhizal infection (3%). Germination of *Glomus fasciculatus* chlamydospores was not inhibited by any sludge treatment (Table 33), indicating that reduction of mycorrhizal infection resulting from sludge amendments did not occur because of failure of spores to germinate.

Nodulation associated with each sludge source followed a pattern similar to that of plant growth (Figure 5). Marked increases in nodulation occurred in the Can, Clev 2.5% and Det 10% treatments, corresponding to seedling growth increases at these levels. However, the large plants in the MV 25% treatment had a relatively low level of nodulation.

Results of these experiments indicate that sludge amendments may not only be beneficial for growth of containerized black locust seedlings, but that preliminary growth response tests can be useful in determining optimum and phytotoxic levels of each particular sludge. With two of the four sludges tested in this investigation, levels of 2.5 and 5% sludge were shown to be beneficial for seedling growth. In one of these three sludges a 10% sludge amendment also enhanced seedling growth. However, concentrations of 25% of each of these sludges resulted in severe phytotoxicity. For each of the sludges tested, therefore, an application rate of 2.5 - 10% would provide some additional plant nutrients with a sufficient margin of safety for protection against phytotoxicity at high rates of sludge amendment. It should be noted that seedlings were not fertilized throughout the 10-week period of this study. Effects of sludge amendment may be enhanced or obscurred by fertilization. The interaction of fertilizer and sludge amendment deserves further study.

The fact that sludge amendment reduced mycorrhizal infection even at relatively low rates of addition to the potting mixture indicates that this practice could result in containerized seedlings having less than optimal levels of mycorrhizal infection at the time of outplanting. Although shoot dry weight and plant height may be good indicators of seedling vigor, nonmycorrhizal seedlings with high shoot-to-root ratios may be poorly adapted for outplanting on adverse sites. For example, seedlings in the 25% MV sludge treatment had the greatest shoot dry weight and height measurements; however, root systems of these seedlings were completely devoid of mycorrhizal infection. If outplanted to sites where mycorrhizal fungus inoculum was low, such seedlings might be unable to obtain adequate

FIGURE 4

Figure 4. Effect of varying concentrations of sludge from four municipal sources on mycorrhizal infection of black locust seedlings 10 weeks after seeding

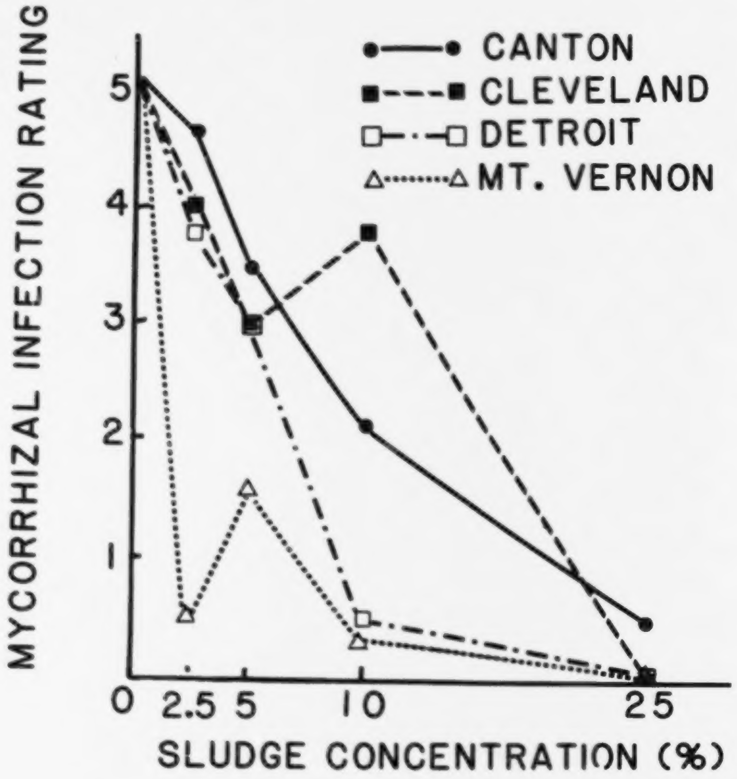
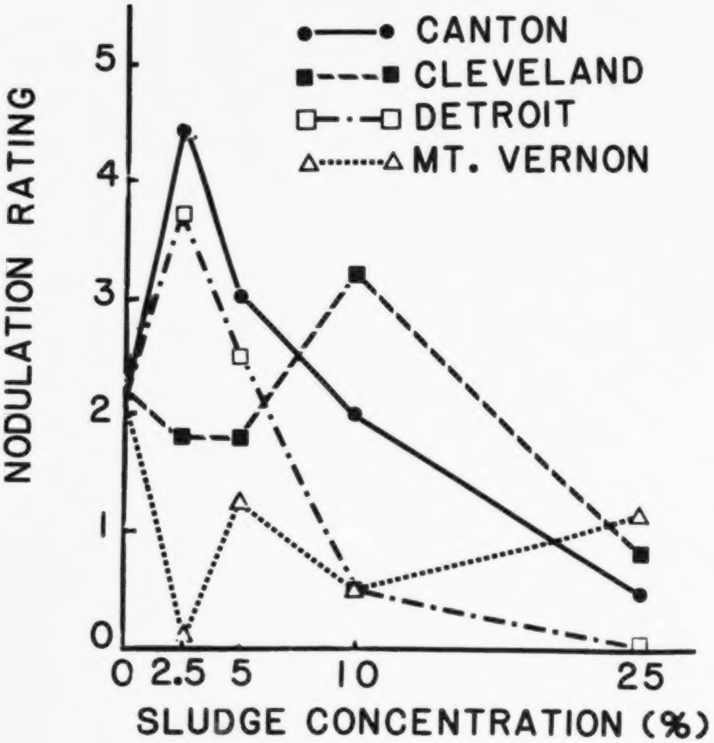


FIGURE 5

Figure 5. Effect of varying concentrations of sludge from four municipal sources on nodulation of black locust seedlings 10 weeks after seeding



nutrients to support continued top growth.

Considering the differences among seedlings from the MV 25% treatment and those from Can, Clev and Det 25% treatments, reduction or elimination of mycorrhizae at the 25% sludge rate must be accounted for by at least two separate mechanisms. It is likely that severely stunted seedlings in the Can, Clev, and Det 25% treatments were unable to translocate adequate levels of carbohydrates to roots to allow for establishment of mycorrhizal infection. This explanation does not seem as likely for the MV 25% treatment since seedlings appeared vigorous. An alternative possibility is the suppression of infection as a result of high P concentration in plants from this treatment. It is well-established that mycorrhizal infection may be suppressed by high concentrations of P in plant tissue (Rhodes & Gerdemann, 1980). However, absence of mycorrhizal infection in plants from the 25% MV sludge treatment cannot be explained on the basis of high P concentrations since the mean concentration of P in plants from the 25% MV treatment was only 0.11%, whereas average concentrations of P in no-sludge control plants was 0.23%. Comparisons of other nutrients analyzed showed similar concentrations between no-sludge control plants and 25% MV plants. These results indicate that the absence of mycorrhizal infection was not directly related to a P fertilizer effect in the high 25% MV sludge treatment. Likewise, germination of G. fasciculatus chlamydospores was not affected by sludge rate from any source (Table 33), indicating that apparent detrimental effects of sludge were not related to this aspect of fungal development. Thus, the inhibition of mycorrhizal infection in the MV 25% treatment is not readily explained by results of the present study.

In the study to determine heavy metal effects on germination and fungus hyphal development, germination of G. macrocarpus chlamydospores generally declined as concentrations of metal ions in the agar medium increased (Figure 6).

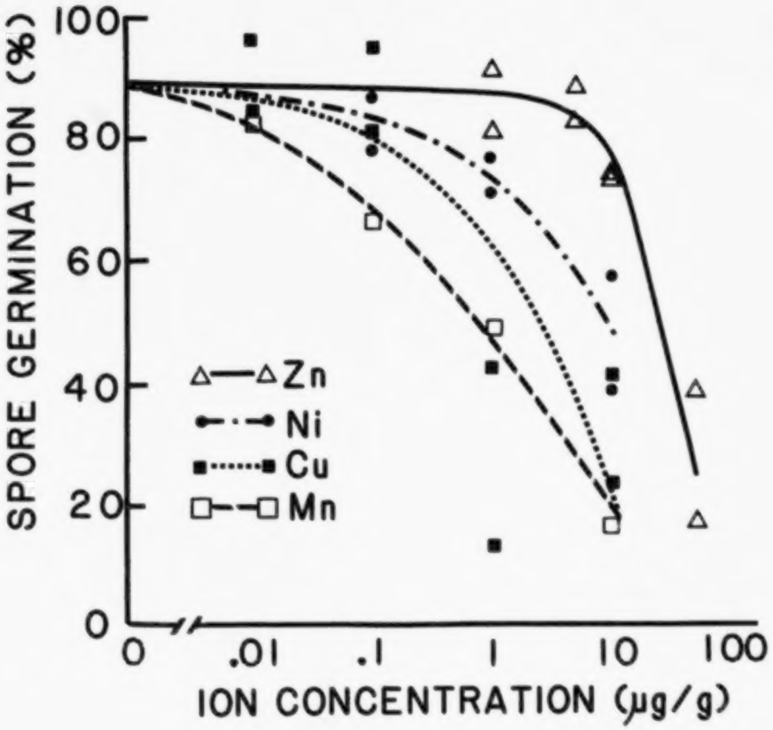
An abrupt decline in germination was seen as Zn^{++} concentration was increased from 10 to 50 µg/g. The equation for spore germination as a function of Zn^{++} concentration was $Y = 1.22\,x + 88.8$, with $R = 0.97$ ($P = 0.01$).

Germination at 1.0 and 10.0 µg Cu/g medium was highly variable. However, it was apparent from means of two experiments that these concentrations of Cu in the medium had a detrimental effect on spore germination. A blue-green discoloration of the contents of many spores incubated on agar amended with 10 µg Cu was apparent within 1 to 2 days after spores were placed on the agar. This discoloration was not seen with other metal-amended agars.

Germ tube growth was also reduced as metal concentrations increased (Table 32). For example, the percentage of spores in which germ tubes were well-developed (Category 3) was reduced from approximately 90% in controls to less than 1% at 10 µg Cu/g medium, and to 2% at 10 µg Ni/g medium, even though approximately 60% of the spores had germinated in each of these treatment combinations.

FIGURE 6

Figure 6. Effect of varying concentrations of agar-medium incorporated zinc, nickel, copper, and manganese on germination of _Glomus macrocarpus_ chlamydospores



An amendment of water agar with sludge also resulted in reduction in germination and germ tube growth (Table 34). As the sludge concentration was increased from 0.1 mg/g to 1.0 mg/g agar, the percentage of spores with extensive germ tube growth was reduced from 67.6% to 1.6%. This indicates a substantial inhibitory effect of sludge at this concentration, even though germination was greater than 80%. Incineration of sludge substantially altered the effects of sludge in the agar (Table 35). There is a 10 fold decrease in the toxicity of incinerated sludge. This suggests that either 1) the organic constituents of the sludge were rendering toxic metals more available, 2) organic sludge components were approximately 10 times more toxic than the metals, or 3) sludge metabolites, e.g. NH_4^+, were more toxic than the metals, the latter two explanations being likely.

COPPER REQUIREMENTS OF CONIFERS

Procedures

A set of three experiments was designed to determine if copper was limiting growth of containerized coniferous seedlings. In the first experiment a 1:1 (v/v) peat-vermiculite (P/V) mix and a 7:3 (v/v) mix of composted hardwood bark and vermiculite (B/V) were used. The P/V pH was increased to 5.5 with hydrated dolomitic lime, while the initial B/V pH was left at 6.9. "Conetainers" (160 ml tubes) were filled with 150 cc of these media and seeded with blue spruce, Douglas-fir, noble fir or eastern white pine. After the seed coats were cast, seedlings were thinned to one per cell. The P/V treatments were fertilized with 20 ml per cell of 150 ppm N, 50 ppm P, 100 ppm K, 65 ppm Ca, 40 ppm Mg, 50 ppm S, 5 ppm Fe, 0.5 ppm Mn, 0.5 ppm B, 0.05 ppm Zn, and 0.01 ppm Mo. The B/V treatments were fertilized with 300 ppm N and other elements at 120% of the rates given above for the P/V mix. Copper as $CuSO_4 \cdot 5H_20$ was added to the fertilizer solutions at final concentrations of 0.00, 0.01, 0.04, 0.16, or 0.64 ppm, resulting in approximately 0.00, 0.05, 0.20, 0.80, and 3.20 µg Cu per cc of P/V mix. A sixth treatment for each mix contained 2% (v/v) digested municipal sewage sludge (GH-An, Table 36), equivalent to 14 µg Cu per cc of container medium. Other elements added in sludge on a µg/cc basis were: N - 552, P - 670, K - 70, Ca - 850, Mg - 100, Fe - 18, Zn - 17, B - 5, Mo - 0.5, Cr - 14, Pb - 4, Cd - 0.3, Ni - 7.7, Hg - 1.2, Na - 56. The sludge treatment was not amended with Cu. Nutrient solutions were applied directly to the media twice weekly, and the trees were watered on other days with deionized water. There were three completely randomized blocks of seven subsamples per replicate (single seedlings) per treatment. The P/V seedlings were measured, harvested, and weighed after 5 months and the B/V seedlings were harvested and weighed after 6 months. Entire shoots of Douglas-fir and noble fir seedlings, but only needles of the blue spruce and white pines were wet-digested and analyzed for Cu.

A second study was conducted with Douglas-fir in the same container type and P/V mix. Before seeding, the mix was amended with drenches of 0, 2, 5, 10, 20, 50, or 100 mg Cu as $CuSO_4 \cdot 5H_2O$ per liter of mix applied in a 20-ml-per-tube aliquot. Trees in 12 randomized-complete blocks of seven seedlings/replicate (588 trees) were fertilized twice weekly with

20 ml/tube of the 120%-strength nutrient solution used previously for the P/V mix. Seedlings were grown for 5 months.

In a third experiment, Douglas-fir seedlings were grown for 4 months in a 3 x 3 completely randomized factorial arrangement of Cu (0, 10, or 100 ppm in a single drench as applied above) and N levels (25, 100, or 250 ppm in the fertilizer solution). These nine treatments were replicated six times with six individuals/replicate, also in 150 cc tubes of P/V, using the standard fertilizer solution of the second experiment (variable N, 60 ppm P, 120 ppm K, plus all micronutrients other than Cu, and deionized water). At the termination of these experiments, no mycorrhizae were seen in the seedling root systems and no seedlings appeared diseased.

Results

In the first experiment in which various inorganic fertilizer and sludge supplements were compared, only sludge treatments substantially improved growth (Table 17). This indicated that the response to sludge was not due to major nutrients, and indeed, foliar concentrations of P, K, Mg and Ca were generally higher in treatments causing less growth. A very close relationship existed between growth and Cu concentrations. Maximum growth of both species occurred only in treatments inducing an accumulation of more than 2.3 ppm foliar Cu. Concentrations of other metals were not associated with growth. Although the pH of different treatments varied (Table 18), it did not appear to substantially affect the above results. The amount of lime-ferric sludge (Lakewood L/F) added to treatment #6 did not improve growth as much as the other sludges. Although the lime-ferric supplement added approximately as much Cu to the medium as did Milorganite (treatment #9), its availability to seedlings was less because of a higher pH of the growth medium and the presence of the Cu in very high pH sludge particles. Milorganite is a dried, activated sludge with greater free acidity than the lime-ferric sludge.

In a second comparison of sludges with other treatments, there was little positive response to any treatment, and finely-ground Milorganite was distinctly toxic (Table 19). The standard treatment, 2% v/v coarse Lakewood sludge, produced the heaviest seedlings. Charcoal, which is an adsorbant of various organic and inorganic substances, did not improve growth, suggesting that absorption of toxic materials is not a major reason for seedling growth improvement due to sludge. Foliar Cu was not analyzed, and it may be that Cu was sufficiently available in all treatments to prevent a dramatic response to added Cu. This is suggested by the high foliar Cu level in the control treatment of another experiment performed in the same greenhouse (Table 20).

In the first experiment to demonstrate the response of conifer seedlings to normal (0.00 to 0.04 ppm) or higher soil Cu levels and to sludge, sludge in the standard peat-vermiculite medium improved growth of all four conifer species (Table 21). A copper supplement substantially improved the growth of Douglas-fir, but not the other three species. Foliar Cu concentrations for the sludge treatment were similar to those achieved by adding 0.16 ppm Cu to the fertilizer solution applied twice weekly.

Sludge appears to improve initial seedling development most. This was especially true in the bark-vermiculite medium, where "bark toxicity" severely limited seedling growth for about 2 months after germination (Table 22). Bark toxicity and chlorosis resulting from either leaching of toxic components from bark or from the adsorption of fertilizer elements (particularly nitrogen) by bark was visibly reduced by the sludge treatment. While peat is known to be a potent adsorber of Cu, Cu deficiency was more severe in the bark mix as indicated by the lower levels of foliar Cu and the response of all four species to Cu. The amount of sludge added was apparently not sufficient to meet the Cu requirements of white pine.

In two experiments to test the efficacy of single, large Cu applications, Cu improved growth of Douglas-fir grown in a peat-vermiculite mix, and this species was able to tolerate excessive Cu loading rates (Table 20, Table 23). The effect of Cu was not related to improved N-fertility in Cu-sufficient treatments (Table 23).

PHOSPHORUS AVAILABILITY IN SLUDGE

Procedures

The design of the primary experiment consisted of 10 replicates of three main factors in 40 treatment combinations (2 x 4 x 5). The factors were 1) addition of mycorrhizal inoculum to half the treatments, 2) addition of 0, 60, 150, or 270 ppm P, and 3) addition of supplemental sludge from four sources plus a fifth control treatment. A Ravenna silt loam was treated with aerated steam at 60 C for 2 hr. to eliminate indigenous mycorrhizal fungi. This soil, with an initial pH of 5.2, 6 ppm Bray #1 P, and a CEC of 13 meq/100 g was treated with potassium sulfate and hydrated lime to achieve exchange site saturations of 75% Ca, 20% Mg, and 5% K. At the end of the experiment, the average pH of the non-sludge treatments was 7.1. Pot cultures of Glomus fasciculatus Gerdemann and Trappe spores and infected wheat roots were added at 2% (v/v). Phosphorus was added as calcium monophosphate (CMP) ground to pass a 0.5 mm screen. Four sludges, Zim-C, Zim-NO, L/F-LW, and AS-M (Table 36) were dried at 70 C, hammer-milled, and added to soil at a rate of 100 µg sludge-P per g soil. Amounts of sludge and sludge elements added to soil are given in Table 26. Five replicates of no-sludge treatments receiving 420 ppm P and five replicates each of the intermediate rates of 30, 105, 210, and 345 ppm P were included to provide more accurate MR and NMR standard curves for P uptake, P concentration, and shoot dry weight. Three other treatments (10 replicates) received North Olmsted sludge (150 ppm) which had either been ground in a hammer mill, crushed to particles 2-10 mm in diameter, or broken into particles 10-30 mm in diameter. These three treatments were included to determine if the degree of sludge dispersal affected P uptake. Pots were filled with approximately 1.5 liters of these soils and seeded after 5 days with Rhizobium-inoculated "Beeson" soybeans (Glycine max Merr.). Shoots were harvested after 7 weeks, dried, digested, and the shoots were analyzed. The non-sludge MR and NMR treatment means for P content and concentration were regressed on several transformations of the CMP levels to produce standard curves with coefficients of determination of .988 in one case and .996 in the other three cases. These standard curves were used to determine "CMP equivalents", the amount of CMP in the control treatment required to equal the P content or P concentration of a sludge treatment mean. This indicated the availability of sludge phosphorus relative to the availability of CMP. Four months after harvest, soil from each pot in the P_{150}, P_{270}, and P_{420} treatments was analyzed for $NaHCO_3$ - extractable P.

In a subsequent experiment, the same soils and sludges were used to determine soil NO_3^- and NH_4^+ concentrations 2, 5, 12, and 27 days after the addition of sludge. Three 25 g samples of moist soil from four replicated pots (300 cc volume) were used for pH, dry weight at 70 C, and extractions.

Results

In a greenhouse experiment to determine the effects of P, Cu, Zn, and sewage sludge (Milorganite) on growth of MR and NMR sweetgum, nonmycorrhizal seedlings responded much more to sludge than did mycorrhizal seedlings (Table 25). Depending on the growth parameter, the growth increment induced by sludge was greater than or equal to that produced by 50 ppm added P for nonmycorrhizal seedlings, but was substantially less than the 50 ppm P increment in mycorrhizal seedlings. This suggested that sludge reduced the availability of P to mycorrhizal plants. An experiment was then conducted with soybeans to determine the effects of Milorganite and various other sludges on P availability to MR and NMR plants.

Milorganite, an activated sludge, contained a high percentage of minimally stabilized nitrogen (Table 26), and consequently generated the highest level of NH_3 in soil (Table 27). Some nitrite accumulated, but not as much as with the alkaline lime-ferric sludge. Milorganite, which had previously reduced growth of mycorrhizal sweetgum, completely eliminated the mycorrhizal response of soybean in the first planting, as indicated by the absence of higher MR shoot weights, and higher Mn, P, Cu, and Zn concentrations at the lower soil P levels (Table 28). Substantial recovery of mycorrhizal activity did not occur in the second planting, and root colonization by MR fungi in this sludge treatment was low, 28% versus 87 - 95%.

At the two highest CMP levels, P added in sludges increased $Na\,HCO_3$ - extractable P 0-80% as much as an equivalent amount of CMP in the first planting, and increased Bray #1 - extractable P 22-72% relative to CMP in the second planting (Table 29).

As the soil P level was increased with CMP, plant P content of NMR soybeans was decreased by sludge relative to the no-sludge standard (Figure 7). In MR plants, sludge either increased (Zimpro treatments) or sharply reduced (lime-ferric-activated sludges) shoot P content relative to CMP treatments (Figure 8).

Phosphorus extractability from soil and availability to plants were neither consistent nor were they closely related to the sludge contents of

FIGURE 7

Figure 7. Phosphorus contents of sludge-treated, nonmycorrhizal soybean shoots at four levels of P expressed as the amount of CMP required to produce the same response without sludge. (Zimpro from Canton & North Olmsted, lime-ferric from Lakewood, and activated sludge from Milwaukee).

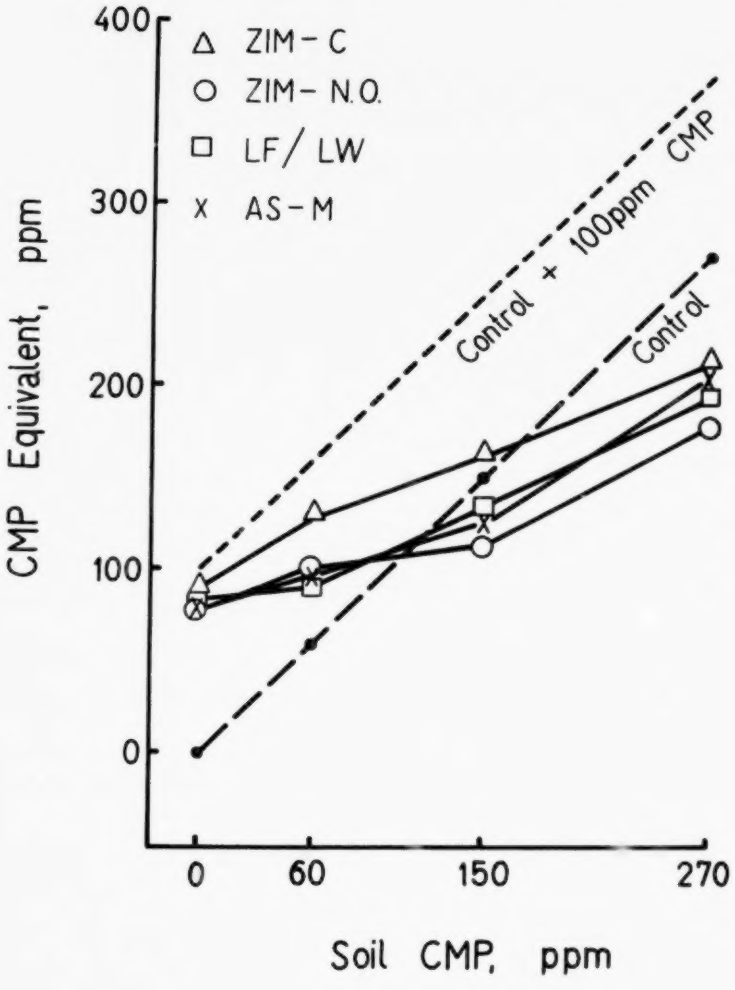
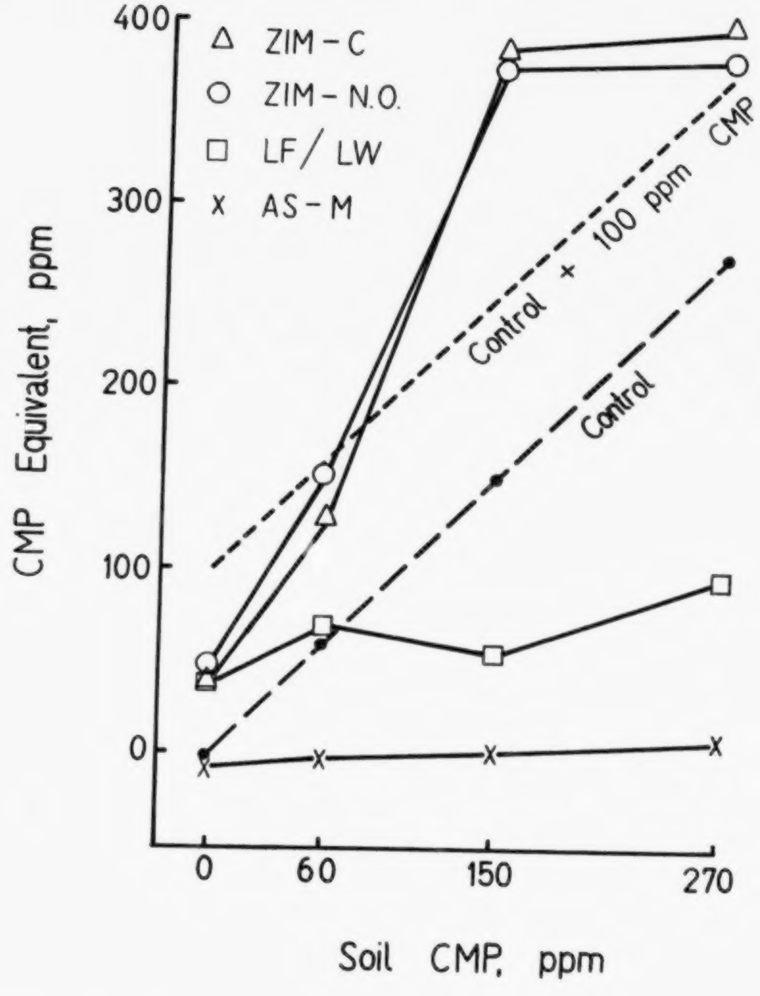


FIGURE 8

Figure 8. Phosphorus contents of sludge-treated, mycorrhizal soybean shoots at four levels of P expressed as the amount of CMP required to produce the same response without sludge. (Zimpro from Canton & North Olmsted, lime-ferric from Lakewood, and activated sludge from Milwaukee).



elements which precipitate P. Although it has been suggested that the ratio of Fe + Al to P in sludge (Table 26) provides the best index of P availability in treated soil, such a relationship was not detected in this study. Bicarbonate-extractable P was somewhat associated with higher pH and sludge Ca levels, and with lower Al levels. Bray #1 - extractable P was inversely related to the amount of Fe added to the soil. Reductions in P uptake by NMR plants were most closely related to levels of added aluminum, while inhibited P uptake in MR plants was associated with NH_3 or NO_2^- accumulation in the soil and probably to high oxygen demand. Thus, sludge effects on P uptake are not straightforward and appear to act in various ways. Phosphorus precipitated in sludge is less soluble (available) than standard fertilizer P. Phosphorus availability determinations for sludge-treated soils are affected by the choice of extraction method, and by interactions of sludge P with the soil and, *vice versa*, by interactions of soil P with the sludge. The fact that sludge increased extractable P in all but one case (where there was no change), but decreased shoot P content or concentration in a number of cases, suggests that sludge also affects P uptake as well as P availability. One must also recognize that heat-dried waste activated sludges are more likely to be phytotoxic than digested sludges. How this occurs in nonmycorrhizal plants was not determined, but may involve P inactivation at or in the roots, deleterious effects on uptake mechanisms, or effects on root morphology. If sludge is toxic enough to inhibit MR infection or function, P uptake is substantially reduced.

Increasing the dispersion of sludge in soil by decreasing the particle size did not affect P uptake, but did increase Zn uptake and decrease Mn uptake (Table 30). In almost all cases those plants infected by mycorrhizal fungi produced greater shoot dry weights for any given sludge treatment than the same sludge treatment without mycorrhizae (Table 31). These differences were generally significant. The only case in which the differences between mycorrhizal and nonmycorrhizal phosphorus contents appears to be insignificant were those in which the dried Milwaukee sewage sludge was used as a treatment. In other cases, the phosphorus contents of mycorrhizal soybeans were significantly greater than the phosphorus contents of nonmycorrhizal plants grown in the same sludge treatment. Again, the copper contents of mycorrhizal plants were substantially greater than those of nonmycorrhizal plants with the exception of those grown in Milwaukee sludge. On the other hand, the manganese contents of nonmycorrhizal plants were generally and significantly higher than the manganese contents of the mycorrhizal plants with the exception of those grown in Milwaukee sludge. In most cases the relationships of mycorrhizal and nonmycorrhizal plants to metal uptake were just reversed for plants grown in Milwaukee sludge compared to plants grown in other sludges.

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TABLE 1. GROWTH OF CONIFER TRANSPLANTS IN SOIL TREATED WITH VARIOUS RATES OF CLEVELAND SLUDGE APPLIED IN 1980 AT THE SECREST SITE

Sludge Loading Rate (MT/ha)	1980	1981	
	Growth (cm)	Growth (cm)	Survival (%)
		BLUE SPRUCE	
0	5.6 B*	9.6 BC	57 C
11	4.7 AB	8.4 BC	60 C
22	5.6 B	10.4 C	55 C
45	5.0 AB	8.1 B	48 BC
90	4.8 AB	7.3 A-C	24 AB
180	4.6 A	5.6 A	9 A
		DOUGLAS-FIR	
0	4.2 A	7.6 B	59 C
11	4.0 A	6.5 AB	60 C
22	4.3 A	6.2 AB	73 C
45	3.9 A	5.9 AB	40 BC
90	4.2 A	4.4 A	18 AB
180	3.7 A	4.1 A	5 A
		FRASER FIR	
0	4.5 AB	5.4 B	69 BC
[illegible]	5.1 B	4.7 AB	88 C
[illegible]	5.1 B	5.0 B	83 C
[illegible]	4.7 AB	4.7 AB	55 B
[illegible]	3.9 A	3.3 A	31 A
180	3.9 A	3.5 AB	18 A

(continued)

TABLE 1. (continued)

Sludge Loading Rate (MT/ha)	1980	1981	
	Growth (cm)	Growth (cm)	Survival (%)
		SCOTCH PINE	
0	3.4 A	10.1 C	40 A-C
11	3.5 A	9.1 BC	46 BC
22	3.8 A	9.5 BC	54 C
45	3.0 A	7.1 AB	23 A-C
90	2.5 A	6.1 AB	8 A
180	2.6 A	5.4 A	15 AB
		E. WHITE PINE	
0	8.6 AB	12.9 B	54 CD
11	9.1 AB	10.9 AB	71 DE
22	10.3 B	11.6 AB	81 E
45	8.8 AB	9.4 AB	37 BC
90	7.9 AB	7.8 AB	16 AB
180	6.3 A	7.6 A	11 A

* Means followed by the same letter do not differ at the 0.05 level.

TABLE 2. GROWTH OF CONIFER TRANSPLANTS AT THE SECREST SITE IN SOIL TREATED WITH VARIOUS RATES OF N. OLMSTED (ZIMPRO) SLUDGE APPLIED IN 1981

Sludge Loading Rate (MT/ha)	1981 Growth (cm)	Total Height in 1982 (cm)	Survival by 1982* (%)
		BLUE SPRUCE	
0	5.5 A	42.6 A	96 C
11	5.1 A	42.6 A	78 AB+
22	5.1 A	42.7 A	86 BC
45	5.3 A	43.2 A	71 A
90	5.4 A	44.2 A	84 B
		DOUGLAS-FIR	
0	4.0 A	36.9 A	85 BC
11	3.6 A	35.8 A	68 A
22	3.9 A	33.9 A	79 AB
45	3.4 A	35.8 A	96 C
90	3.5 A	37.0 A	70 A
		FRASER FIR	
0	8.7 A	41.2 A	89 B
11	6.8 A	38.0 A	59 A
22	7.6 A	41.1 A	75 AB
45	7.8 A	40.9 A	74 AB
90	6.0 A	40.1 A	71 AB

(continued)

TABLE 2. (continued)

Sludge Loading Rate (MT/ha)	1981 Growth (cm)	Total Height in 1982 (cm)	Survival by 1982 (%)
		SCOTCH PINE	
0	4.4 A	45.4 A	74 A
11	4.7 A	49.2 A	65 A
22	4.1 A	47.6 A	68 A
45	3.8 A	49.2 A	58 A
90	4.2 A	50.1 A	58 A
		E. WHITE PINE	
0	6.7 A	30.0 A	73 A
11	6.6 A	30.8 A	71 A
22	6.8 A	30.6 A	79 A
45	6.5 A	32.8 A	61 A
90	6.9 A	31.6 A	65 A

* Means followed by the same letter do not differ significantly at the 0.05 level.

+ Survival in the 11, 22, and 90 MT/ha treatments was reduced by one of four replicates of these rates being in a poorly drained area.

TABLE 3. GROWTH OF CONIFER TRANSPLANTS AT THE DUNHAM SITE IN SOIL TREATED WITH DIFFERENT RATES OF CLEVELAND SLUDGE APPLIED IN 1980

Sludge Loading Rate (MT/ha)	Species	1981		1982	
		Growth (cm)	Percent Survival	Total Height (cm)	Percent Survival
0	BLUE SPRUCE	4.6 A*	79 B	39.9 A	77 B
11		4.0 A	61 AB	37.6 A	69 B
22		4.2 A	72 AB	40.0 A	61 AB
45		4.2 A	45 A	39.7 A	42 A
90		4.6 A	63 AB	38.0 A	59 AB
180		4.0 A	49 A	39.7 A	43 A
0	DOUGLAS-FIR	3.5 A	66 A	38.6 A	48 C
11		3.1 A	47 A	35.4 A	34 BC
22		2.9 A	63 A	37.3 A	38 BC
45		3.1 A	30 A	34.7 A	16 A
90		3.5 A	47 A	36.5 A	38 BC
180		3.1 A	33 A	33.8 A	21 AB
0	FRASER FIR	6.7 B	70 A	35.7 B	67 B
11		6.5 B	69 A	31.6 A	55 AB
22		6.2 AB	75 A	34.6 AB	69 B
45		6.2 AB	34 A	36.7 B	30 A
90		6.3 AB	45 A	35.9 B	39 A
180		4.9 A	33 A	31.3 A	33 A

(continued)

TABLE 3. (continued)

Sludge Loading Rate (MT/ha)	Species	1981		1982	
		Growth (cm)	Percent Survival	Total Height (cm)	Percent Survival
0	SCOTCH PINE	5.7 A	50 B	44.0 A	53 C
11		4.6 A	55 B	46.8 A	53 C
22		4.8 A	48 B	48.0 A	45 BC
45		5.3 A	34 AB	47.2 A	36 B
90		3.9 A	45 AB	44.8 A	30 AB
180		4.2 A	33 A	46.5 A	21 A
0	WHITE PINE	7.3 B	83 A	32.6 B	77 B
11		6.3 AB	78 A	29.4 A	75 B
22		6.2 AB	73 A	30.1 AB	67 B
45		6.1 AB	64 A	28.2 A	61 AB
90		5.8 A	70 A	29.7 AB	69 B
180		6.2 AB	64 A	27.7 A	44 A

* Means followed by the same letter do not differ significantly at the 0.05 level by Duncan's Modified LSD Test.

TABLE 4. COMPARATIVE GROWTH OF CONIFER TRANSPLANTS AND WEEDS AT THE SECREST AND DUNHAM SITES DURING THE FIRST SUMMER FOLLOWING SLUDGE APPLICATION

Sludge Loading Rate (MT/ha)	Average+ Conifers Height (cm)		Weeds (Dry wt.) (g/m^2)	
	Secrest	Dunham	Secrest	Dunham
0	5.3 BC*	4.1 C	511 A	203 A
11	5.3 BC	4.1 C	697 A	347 A
22	5.8 C	4.1 C	605 A	495 A
45	5.1 BC	3.7 BC	686 A	468 A
90	4.7 AB	3.1 B	978 A	668 A
180	4.2 A	2.2 A	510 A	455 A

* Means within columns followed by the same letter are not different at the P=.05 level according to a Duncan's Modified LSD Test.

+ Average tree height per sludge treatment over all conifer species.

TABLE 5. GROWTH AND SURVIVAL OF YELLOW-POPLAR TRANSPLANTED IN 1981 AT THE SECREST SITE IN SOIL TREATED WITH VARIOUS RATES OF N. OLMSTED (APPLIED IN 1981) OR CLEVELAND (APPLIED IN 1980) SLUDGES

Sludge Loading Rate (MT/ha)	1981		1982	
	Growth (cm)	Percent Survival	Growth (cm)	Percent Survival
		NORTH OLMSTED		
0	13.8 A*	81 A	57.8 A	70 B
11	18.8 A	81 A	73.2 A	73 B
22	17.3 A	91 A	67.2 A	75 B
45	16.4 A	75 A	47.5 A	53 B
90	21.9 A	78 A	47.8 A	54 B
		CLEVELAND		
0	15.9 A	91 A	61.6 A	78 B
11	14.7 A	88 A	78.9 B	80 B
22	14.1 A	94 A	67.2 A	83 B
45	13.5 A	88 A	59.9 A	77 B
90	15.3 A	81 A	66.8 A	79 B
180	17.7 A	72 A	73.5 A	48 A

* Means followed by the same letter are not different at the 0.05 level according to a Duncan's Modified LSD Test.

TABLE 6. SHOOT GROWTH AND FOLIAR ANALYSES OF 2-0[#] EASTERN WHITE PINE SEEDLINGS[+]

Sludge Loading Rate (MT/ha)	Growth (cm)	Element			
		P	K	Mg	Ca
		Percent dry weight			
		SECREST			
0	8.6 AB[*]	.18 BC	.47 A	.14 B	.23 A
11	9.1 AB	.19 C	.52 A	.13 AB	.25 A
22	10.3 B	.18 BC	.52 A	.13 AB	.26 A
45	8.8 AB	.17 AB	.53 A	.12 AB	.22 A
90	7.9 AB	.15 A	.50 A	.12 AB	.18 A
180	6.3 A	.14 A	.43 A	.11 A	.22 A
		DUNHAM			
0	7.1 B	.16 A	.46 A	.14 D	.28 B
11	7.2 B	.16 A	.43 A	.12 C	.30 B
22	7.0 B	.17 A	.44 A	.11 B	.23 AB
45	7.0 B	.17 A	.47 A	.11 B	.20 A
90	5.5 AB	.16 A	.41 A	.10 AB	.19 A
180	4.4 A	.16 A	.27 A	.08 A	.23 AB

(continued)

TABLE 6. (continued)

Sludge Loading Rate (MT/ha)	Element					
	Fe	Mn	Zn	Cu	Na	Cr
	(μg/g)					
			SECREST			
0	153 A	86 AC	43 A	3.8 A	4.6 AB	4.1 A
11	140 A	77 BC	48 A	3.3 A	5.2 AB	3.7 A
22	143 A	76 BC	40 A	3.0 A	4.0 A	3.5 A
45	169 A	76 BC	36 A	4.1 A	4.9 AB	3.8 A
90	211 B	61 AB	35 A	7.1 A	7.1 B	4.9 A
180	173 A	52 A	32 A	4.8 A	7.4 B	4.2 A
			DUNHAM			
0	127 AB	472 B	49 A	4.4 A	3.1 A	3.8 A
11	115 A	274 AB	48 A	5.0 A	3.9 A	3.5 A
22	135 AB	141 A	36 A	5.2 A	3.7 A	5.0 A
45	156 AB	155 A	35 A	6.0 A	3.7 A	5.5 A
90	190 AB	79 A	43 A	5.3 A	5.2 A	5.5 A
180	216 B	196 AB	47 A	4.3 A	4.0 A	4.0 A

2-0 seedlings means 2 years of age and not previously transplanted.

* Means followed by the same letter do not differ significantly at the 0.05 level according to a Duncan's Modified LSD Test.

+ Seedlings were outplanted in the spring of 1980 and were harvested in the fall of the same year.

TABLE 7. FOLIAR ANALYSES OF 2-0# EASTERN WHITE PINE SEEDLINGS TRANSPLANTED IN 1981 AT THE SECREST SITE TREATED WITH DIFFERENT RATES OF NORTH OLMSTED (APPLIED IN 1981) OR CLEVELAND (APPLIED IN 1980) SEWAGE SLUDGE

Sludge Loading Rate (MT/ha)	Element			
	P	K	Ca	Mg
	(Percent dry weight)			
	NORTH OLMSTED			
0	0.18 A*	0.90 A	0.33 A	0.20 A
11	0.16 A	0.81 A	0.41 A	0.20 A
22	0.17 A	0.79 A	0.39 A	0.21 A
45	0.17 A	0.81 A	0.38 A	0.19 A
90	0.16 A	0.78 A	0.39 A	0.20 A
	CLEVELAND			
0	0.17 B	0.88 C	0.41 A	0.21 B
11	0.17 B	0.73 A	0.46 A	0.22 B
22	0.16 B	0.78 AB	0.42 A	0.21 B
45	0.17 B	0.76 AB	0.43 A	0.19 AB
90	0.15 B	0.75 AB	0.45 A	0.19 AB
180	0.13 A	0.79 B	0.48 A	0.18 A

(continued)

TABLE 7. (continued)

Sludge Loading Rate (MT/ha)	Element Fe (µg/g)	Mn	Zn	Cu
		NORTH OLMSTED		
0	356 A	154 A	45 A	3.5 A
11	358 A	221 A	40 A	4.0 A
22	389 A	138 A	38 A	4.2 A
45	395 A	123 A	39 A	4.2 A
90	401 A	129 A	36 A	4.3 A
		CLEVELAND		
0	278 A	153 A	38 A	4.0 AB
11	268 A	180 A	37 A	4.1 AB
22	256 A	171 A	36 A	3.8 A
45	224 A	127 A	35 A	3.6 A
90	336 A	175 A	34 A	4.9 B
180	301 A	109 A	31 A	3.3 A

# Two-year-old seedlings not previously transplanted.

* Means followed by the same letter do not differ significantly at the 0.05 level by Duncan's Modified LSD Test.

TABLE 8. GROWTH AND MYCORRHIZAL INCIDENCE FOR 2-0[#] EASTERN WHITE PINE SEEDLINGS TRANSPLANTED AT THE SECREST SITE TREATED WITH DIFFERENT RATES OF NORTH OLMSTED (APPLIED 1981) OR CLEVELAND (APPLIED 1980) SLUDGE

Sludge Loading Rate (MT/ha)	Dry Weight Shoot (g)	Dry Weight Root (g)	Shoot/Root	Root[*] Rating	Mycorrhizal Incidence[+] (Percent)
		NORTH OLMSTED			
0	3.89 A[‡]	2.34 B	1.7 A	2.3 A	65 AB
11	3.13 A	2.25 AB	1.5 A	2.4 AB	67 AB
22	3.96 A	2.60 B	1.5 A	2.9 B	80 B
45	3.73 A	2.53 B	1.5 A	2.8 AB	63 AB
90	2.47 A	1.60 A	1.6 A	2.2 A	51 A
		CLEVELAND			
0	3.69 A	2.39 A	1.6 A	2.8 AB	87 B
11	4.01 A	2.93 A	1.4 A	2.9 AB	89 B
22	4.09 A	3.01 A	1.4 A	3.0 B	84 B
45	3.63 A	2.42 A	1.5 A	3.0 B	83 B
90	2.89 A	2.18 A	1.5 A	2.5 AB	66 AB
180	3.35 A	2.17 A	1.5 A	2.3 AB	50 A

[#] Two-year old seedlings not previously transplanted.

[*] 0 = no lateral roots to 5 = extensive feeder root development.

[+] Percentage of transplants with apparent mycorrhizal infection. Trees were planted in the spring of 1981 and were harvested in late summer.

[‡] Means followed by the same letter do not differ significantly at the 0.05 level according to a Duncan's Modified LSD Test.

TABLE 9. ROOT AND SHOOT GROWTH OF NINE TREE SPECIES SEEDED IN SLUDGE-TREATED SOIL AT THE ZANESVILLE STATE TREE NURSERY IN 1980

Treatment	HARDWOODS				
	Root Dry Weight		Shoot Dry Weight		
	BL[*]	RO	BL	RO	YP
	(g)				
None	0.08 A[+]	1.08 A	0.65 A	2.05 A	0.59 A
120 kg/ha N[‡]	0.09 AB	0.90 A	0.88 AB	1.68 A	1.09 B
35 MT/ha Detroit	0.13 AB	1.53 A	1.02 B	2.49 A	0.92 B
80 MT/ha Detroit	0.10 AB	0.82 A	0.91 AB	1.87 A	1.49 C
35 MT/ha Mt. Vernon	0.10 AB	1.01 A	0.83 AB	1.63 A	0.91 B
80 MT/ha Mt. Vernon	0.16 B	1.29 A	1.17 B	1.74 A	1.16 B

Treatment	CONIFERS					
	Shoot Dry Weight					
	BS	DF	NF	WP	VP	SP
	(mg)					
None	20 A	68 A	48 A	51 A	91 A	79 AB
120 kg/ha N	24 A	76 A	46 A	60 A	97 A	91 B
35 MT/ha Detroit	23 A	69 A	42 A	57 A	90 A	74 AB
80 MT/ha Detroit	18 A	65 A	39 A	52 A	96 A	85 AB
35 MT/ha Mt. Vernon	25 A	70 A	44 A	56 A	89 A	75 AB
80 MT/ha Mt. Vernon	18 A	63 A	39 A	47 A	83 A	65 B

[*] BL = black locust, RO = red oak, YP = yellow-poplar, BS = blue spruce, DF = Douglas-fir, NF = noble fir, WP = eastern white pine, VP = Virginia pine, SP = Scotch pine.

[+] Means followed by the same letter are not different at the 0.05 level according to a Duncan's Modified LSD Test.

[‡] N added as NH_4NO_3.

TABLE 10. ELEMENT ANALYSES OF YELLOW-POPLAR SHOOTS AND BLACK LOCUST LEAVES FROM THE ZANESVILLE STATE TREE NURSERY IN THE FALL OF 1980

Treatment	P	K	Mg	Ca	Fe	Mn	Zn	Cu	Cr
	Percent Dry Wt.				(μg/g)				
					YELLOW-POPLAR				
None	.14 AB	1.42 A	.21 AB	.96 A	341 D	78 B	20 A	5.3 B	10 A
120 kg/ha N*	.13 A	1.43 A	.22 BC	.93 A	236 AB	85 B	15 A	2.9 A	12 A
35 MT/ha Det.	.14 AB	1.50 A	.20 AB	1.00 A	302 CD	70 AB	29 B	6.9 BC	12 A
80 MT/ha Det.	.18 C	1.36 A	.21 AB	1.01 A	276 BC	61 A	37 C	9.3 D	14 A
35 MT/ha Mt. V.	.16 B	1.38 A	.19 A	.84 A	277 BC	60 A	19 A	6.3 BC	11 A
80 MT/ha Mt. V.	.18 C	1.45 A	.24 C	.95 A	212 A	55 A	18 A	7.3 C	9 A
					BLACK LOCUST				
None	.24 AB	1.58 A	.22 B	1.57 C	583 C	70 B	29 A	6.1 A	6 A
120 kg/ha N	.21 A	1.50 A	.22 B	1.50 BC	290 AB	78 B	21 A	7.7 AB	5 A
35 MT/ha Det.	.27 B	1.62 A	.20 AB	1.50 BC	320 A-C	50 A	45 B	6.0 A	7 A
80 MT/ha Det.	.25 AB	1.63 A	.21 B	1.20 AB	479 BC	53 A	45 B	8.0 AB	9 A
35 MT/ha Mt. V.	.28 B	1.63 A	.18 A	1.13 A	424 A-C	50 A	30 A	10.8 B	13 A
80 MT/ha Mt. V.	.26 B	1.67 A	.18 A	1.10 A	214 A	54 A	22 A	9.9 B	9 A

* N added as NH_4NO_3.

TABLE 11. GROWTH AND FOLIAR ELEMENT CONCENTRATIONS FOR SIX TREE SPECIES AS AFFECTED BY SLUDGE AND FERTILITY TREATMENTS AT THE ZANESVILLE STATE TREE NURSERY IN 1981

Treatment	Root Dry Wt.	Shoot Dry Wt.	P	K	Ca	Mg	Fe	Mn	Cu	Zn
	(g)	(g)	Percent dry wt				(µg/g)			
					WHITE OAK					
None	3.25 BC‡	2.30 B	.15 B	1.15 BC	1.81 C	.27 D	38 A	154 D	6.9 A	19 AB
120 kg/ha N+	3.82 BC	2.36 B	.14 AB	1.01 AB	1.68 BC	.27 D	38 A	108 BC	7.8 A	19 AB
35 MT/ha Det	2.84 AB	2.33 B	.14 AB	1.13 BC	1.55 B	.25 D	48 AB	114 BC	8.2 A	21 A-C
80 MT/ha Det	2.26 A	1.69 A	.14 AB	1.09 A-C	1.54 B	.27 BC	63 B	143 CD	8.9 A	26 C
200 MT/ha Det	3.09 BC	2.06 BC	.11 A	1.23 C	1.28 A	.23 A	57 AB	65 A	7.9 A	34 D
35 MT/ha MV	3.31 BC	2.12 AB	.14 AB	1.05 AB	1.56 B	.25 B	46 AB	133 CD	6.8 A	18 A
80 MT/ha MV	3.32 BC	2.07 AB	.14 AB	1.02 AB	1.72 BC	.26 C	48 AB	124 B-D	8.6 A	19 A
200 MT/ha MV	3.40 C	2.02 AB	.15 B	0.98 A	1.62 B	.27 CD	53 AB	95 AB	8.8 A	24 BC
					SYCAMORE					
None	4.71 A	11.10 A	.20 AC	2.40 B-D	1.20 B-D	.34 BC	110 A	85 DE	6.7 A	23 A
120 kg/ha N	6.81 A	17.85 A	.18 AB	2.08 AB	1.04 AB	.35 B-D	76 A	54 A	7.1 AB	23 A
35 MT/ha Det	4.42 A	9.95 A	.16 A	2.43 CD	1.21 CD	.31 A	76 A	69 B	6.8 A	23 A
80 MT/ha Det	-	-	.19 AC	2.31 A-D	1.15 A-D	.35 B-D	116 A	92 E	7.7 A-C	25 A
200 MT/ha Det	11.67 B	37.80 B	.17 A	2.62 D	1.31 D	.32 A	86 A	72 CD	9.5 D	31 B
35 MT/ha MV	5.91 A	16.25 A	.23 C	2.19 A-C	1.09 A-C	.33 AB	112 A	64 A-C	8.6 CD	26 A
80 MT/ha MV	4.60 A	12.12 A	.22 BC	2.20 A-C	1.14 A-C	.37 D	78 A	58 AB	8.3 B-D	21 A
200 MT/ha MV	4.70 A	11.63 A	.21 AC	1.98 A	0.99 A	.36 CD	95 A	64 A-C	8.4 CD	21 A

(continued)

TABLE 11. (continued)

Treatment	Root Dry Wt.	Shoot Dry Wt.	P	K	Ca	Mg	Fe	Mn	Cu	Zn
	(g)	(g)	Percent dry wt				(µg/g)			
					YELLOW-POPLAR					
None	1.30 A	2.82 BC	.21 BC	0.63 AB	1.82 A	.36 B	209 A	141 B	6.7 A-C	22 A
120 kg/ha N	2.24 B	3.77 BC	.17 AB	0.57 AB	1.58 AB	.36 B	225 A	92 A	6.0 AB	20 A
35 MT/ha Det	1.16 A	1.83 A	.17 AB	0.60 AB	1.47 AB	.30 A	205 A	75 A	5.8 A	25 A
80 MT/ha Det	-	-	-	0.53 B	1.26 B	.38 AB	315 A	-	4.4 A	-
200 MT/ha Det	2.48 B	4.05 C	.15 A	0.67 AB	1.64 AB	.31 A	331 AB	93 A	7.2 BC	32 B
35 MT/ha MV	2.19 B	3.72 BC	.27 C	0.58 AB	1.86 A	.37 B	244 A	130 B	9.0 D	34 B
80 MT/ha MV	1.82 AB	3.32 BC	.27 C	0.63 AB	1.80 A	.37 B	210 A	90 A	8.0 CD	24 A
200 MT/ha MV	1.38 A	2.30 B	.19 AB	0.69 A	1.60 AB	.35 B	425 B	91 A	7.2 BC	23 A
					BLACK LOCUST					
None	10.70 A	35.73 A	.20 AB	1.33 A	1.33 BC	.17 BC	150 A	175 C	4.9 A	17 A
120 kg/ha N	9.29 A	34.28 A	.24 BC	1.32 A	1.18 A-C	.18 BC	176 AB	125 AB	8.1 B	13 A
35 MT/ha Det	7.57 A	27.01 A	.18 A	1.44 A	1.61 C	.21 CD	211 AB	175 C	7.0 B	33 B
80 MT/ha Det	-	-	.21 AB	1.33 A	1.53 AB	.19 B-D	289 B	194 C	8.3 B	39 B
200 MT/ha Det	7.46 A	24.71 A	.22 A-C	1.48 A	1.19 A-C	.18 BC	160 A	141 AB	7.5 B	38 B
35 MT/ha MV	-	-	.31 D	1.30 A	0.85 A	.10 A	155 A	114 A	7.3 B	15 A
80 MT/ha MV	5.90 A	22.02 A	.30 D	1.48 A	1.12 AB	.15 B	284 B	160 B	8.1 B	15 A
200 MT/ha MV	10.03 A	38.10 A	.27 CD	1.17 A	1.17 A-C	.22 D	272 AB	138 AB	12.3 C	16 A

(continued)

TABLE 11. (continued)

Treatment	Root Dry Wt.	Shoot Dry Wt.	P	K	Ca	Mg	Fe	Mn	Cu	Zn
	(g)	(g)	Percent dry wt				(µg/g)			
					VIRGINIA PINE					
None	0.59 AB	3.07 BC	.25 A	.57 A	0.44 A	.09 A	217 B	160 A	4.4 B	46 C
120 kg/ha N	0.64 B	3.54 C	.23 A-C	.53 A	0.42 A	.08 A	176 B	104 AB	4.3 BC	32 C
35 MT/ha Det	0.56 AB	2.57 AB	.18 D	.53 A	0.47 A	.07 B	246 B	90 B	3.5 C	63 B
80 MT/ha Det	0.49 A	2.44 AB	.21 BC	.54 A	0.47 A	.08 A	436 A	140 AB	5.2 AB	90 A
200 MT/ha Det	0.92 C	4.89 D	.23 AB	.56 A	0.44 A	.09 A	254 B	117 AB	5.9 A	103 A
35 MT/ha MV*	-	-	-	-	-	-	-	-	-	-
80 MT/ha MV	0.45 A	2.11 A	.20 CD	.53 A	0.48 A	.08 A	257 B	95 B	3.4 C	31 C
200 MT/ha MV	0.65 AB	3.02 A-C	.23 A-C	.53 A	0.45 A	.08 A	227 B	133 AB	5.1 AB	34 C
					RED MAPLE					
None	1.78 A-C	4.98 BC	.26 A	.71 A	1.16 A	.30 A	220 A	131 A	8.1 A	44 BC
120 kg/ha N	1.99 C	5.41 C	.17 C	.70 A	1.08 A	.30 A	235 A	101 A	7.2 AB	22 D
35 MT/ha Det	1.44 A	3.57 A	.21 BC	.78 A	1.02 A	.30 A	226 A	88 A	6.6 AB	45 BC
80 MT/ha Det	1.42 A	3.47 A	.20 BC	.78 A	0.97 A	.30 A	285 A	164 A	6.7 AB	62 B
200 MT/ha Det	1.93 BC	5.64 C	.15 C	.78 A	1.12 A	.30 A	283 A	131 A	5.4 B	90 A
35 MT/ha MV*	-	-	-	-	-	-	-	-	-	-
80 MT/ha MV	1.51 AB	3.98 AB	.26 A	.68 A	0.91 A	.30 A	264 A	131 A	7.8 A	31 CD
200 MT/ha MV	1.98 C	5.09 BC	.24 B	.74 A	1.13 A	.30 A	335 A	131 A	7.8 A	35 CD

* No data available for Virginia pine or red maple.

+ N added as NH_4NO_3.

‡ Values in a given column followed by the same letter are not different at the 0.01 level by a DMRT.

TABLE 12. ORGANIC MATTER, WATER CONTENT, WATER INTAKE RATE, AND AGGREGATE STABILITY OF SLUDGE-TREATED SOILS AT THE ZANESVILLE STATE TREE NURSERY - SUMMER 1982

Treatment	June		July		
	Organic Matter	Water Content	Water Content	Water Intake	Aggregate Mean Diameters+ GMD
	Percent		(%)	(cm/min.)	(%)
No sludge	2.7 AB*	14.6 AB	15.5 A	0.60 BC	1.15 A
120 kg/ha N	3.0 B	14.7 AB	15.1 A	0.41 AB	1.13 A
35 MT/ha Detroit	2.7 AB	14.8 AB	15.1 A	0.69 BC	1.14 A
80 MT/ha Detroit	2.4 A	15.2 B	15.4 A	0.69 BC	1.17 A
200 MT/ha Detroit	4.7 C	16.9 C	17.7 B	0.58 BC	1.18 A
35 MT/ha Mt. Vernon	2.9 B	15.0 AB	16.1 A	0.52 A-C	1.14 A
80 MT/ha Mt. Vernon	3.0 B	14.4 A	15.5 A	0.27 A	1.15 A
200 MT/ha Mt. Vernon	3.2 B	15.7 B	15.7 A	0.93 C	1.16 A

* Means followed by the same letter do not differ significantly at the 0.05 level by Duncan's Modified LSD Test.

+ Geometric mean diameters. (Kemper and Chepil, 1965).

TABLE 13. GROWTH OF FOUR GREENHOUSE-GROWN CONIFERS IN A PEAT-VERMICULITE MEDIUM WITH AND WITHOUT A SLUDGE AMENDMENT

		1980*				1981	
Species	Sludge	Height	Diameter	Root Wt.	Shoot Wt.	Height	Diameter
		(cm)	(mm)	(g)	(g)	(cm)	(mm)
Blue Spruce	0	13.6 A+	2.8 A	0.82 A	2.68 A	22.7 A	3.0 A
	+	19.0 B	3.7 B	1.66 B	5.63 B	27.9 B	3.8 B
Douglas fir	0	12.6 A	2.8 A	0.81 A	2.36 A	21.3 A	3.0 A
	+	19.3 B	3.5 B	1.63 B	5.30 B	28.1 B	3.7 B
Noble Fir	0	10.4 A	3.2 A	1.08 A	2.35 A	15.8 A	3.4 A
	+	14.1 B	3.8 B	1.84 B	3.80 B	18.9 B	3.7 B
E. White Pine	0	6.2 A	2.5 A	0.60 A	1.65 A	16.1 A	2.5 A
	+	6.9 B	3.4 B	1.58 B	3.34 B	18.3 B	3.0 B

* Figures for 1980 are the averages of the most vigorous 30 seedlings per treatment; 1981 figures pertain to all seedlings planted in similar containers and sludge treatments in 1981.

+ Means in a given pair followed by the same letter are not different at the 0.05 level.

TABLE 14. GROWTH AND SURVIVAL OF CONTAINERIZED CONIFERS IN THE GREENHOUSE (SEEDED 1980) MEASURED IN 1981 AND AFTER 1 YEAR (1982) FOLLOWING OUTPLANTING

Container	Sludge	1981 (Greenhouse) Height	Diameter	Root Dry Wt.	Shoot Dry Wt.	Shoot/Root	1982 (Field) Survival	Height	Diameter
	%(v/v)	(cm)	(mm)	(g)	(g)		(%)	(cm)	(mm)
					BLUE SPRUCE				
Tube - 10[‡]	0[+]	12.3 BC[*]	2.57 C	0.72 CD	2.29 C	3.23 AB	95 AB	22.0 A	6.9 AB
Book - 11	0	12.8 C	2.65 C	0.59 BC	2.53 CD	4.06 D	100 B	22.3 AB	6.3 A
Tarpaper- 8	0	11.0 AB	1.88 A	0.23 A	1.40 AB	5.99 EF	100 B	20.9 A	7.5 AB
Styro. - 21	0	14.7 E	3.27 E	1.28 EF	3.92 E-G	3.27 AB	85 A	24.1 AB	8.0 BC
Book - 22	0	13.3 CD	3.29 EF	0.73 FG	2.46 CD	3.64 BC	100 B	24.1 AB	7.8 BC
Tarpaper- 6	0	10.4 A	2.25 B	0.41 B	1.25 A	3.24 AB	95 AB	22.6 AB	6.1 A
Tube - 40	0	15.4 E	3.14 E	1.26 EF	3.46 D	2.72 A	85 A	24.7 AB	9.3 DE
Book - 45	0	18.7 F	3.63 FG	1.30 FG	4.09 FG	3.56 BC	85 A	32.7 DE	10.6 E-G
Tube - 10	4	15.1 E	2.92 DE	1.03 DE	3.13 D	3.23 AB	100 B	26.1 BC	7.8 BC
Book - 11	4	17.9 F	3.15 E	1.41 EF	4.70 G	3.49 BC	100 B	29.2 CD	9.1 CD
Tarpaper- 8	4	14.8 C-E	2.66 CD	0.31 A	2.08 BC	7.07 F	95 AB	26.1 BC	7.2 AB
Styro. - 21	4	18.2 F	3.81 G	1.54 F	7.51 IJ	5.02 C-E	95 AB	30.9 D	11.0 GH
Book - 22	4	19.6 C-G	4.10 H	1.98 G	5.96 H	3.08 AB	100 B	33.8 DE	10.8 FG
Tarpaper- 6	4	23.0 H	4.25 H	1.03 DE	6.94 HI	5.84 EF	100 B	38.7 F	12.3 HI
Tube - 40	4	20.6 G	4.28 H	3.30 H	6.57 H	1.81 A	100 B	36.1 EF	11.8 GH
Book - 45	4	22.5 H	4.16 H	2.64 H	8.18 J	3.23 AB	100 B	37.9 F	13.0 I
BR 3-1		19.5 FG	4.40 H	1.80 G	2.75 CD	2.33 A	90 AB	31.8 DE	9.5 D-F

(continued)

TABLE 14. (continued)

Container	Sludge	1981 (Greenhouse) Height	Stem Diameter	Root Dry Wt.	Shoot Dry Wt.	Shoot/Root	1982 (Field) Survival	Height	Stem Diameter
	%(v/v)	(cm)	(mm)	(g)	(g)		(%)	(cm)	(mm)
DOUGLAS-FIR									
Tube - 10	0	10.6 A	2.54 C	0.70 CD	1.72 A	2.56 A	70 A	16.0 A	4.9 A
Book - 11	0	13.1 B	2.95 D	0.78 D	2.48 B	3.41 AB	95 BC	22.7 BC	6.9 BC
Tarpaper-8	0	11.1 A	1.89 A	0.25 A	1.32 A	5.46 D	85 A-C	19.1 AB	4.9 A
Styro. - 21	0	10.7 A	2.85 D	0.67 CD	2.41 B	3.64 A-C	100 C	18.5 AB	6.4 BC
Book - 22	0	13.4 B	3.00 D	0.82 DE	2.70 B	3.28 AB	90 BC	22.4 BC	6.7 BC
Tarpaper-6	0	10.7 A	2.21 B	0.54 BC	1.53 A	2.94 A	90 BC	19.6 AB	5.5 AB
Tube - 40	0	14.9 CD	3.41 F	1.25 GH	2.74 B	2.71 A	100 C	22.2 BC	7.3 CD
Book - 45	0	16.3 DE	3.57 F	1.43 H	4.01 C	2.80 A	100 C	27.3 DE	9.0 EF
Tube - 10	4	15.5 CD	3.14 E	0.99 EF	3.09 BC	3.14 AB	100 C	26.1 BC	7.8 BC
Book - 11	4	16.9 EF	3.02 DE	1.16 FG	3.91 C	3.39 AB	95 BC	28.7 DE	8.5 DE
Tarpaper-8	4	14.3 C	2.43 C	0.44 B	2.80 B	6.51 E	85 A-C	21.6 BC	5.7 AB
Styro. - 21	4	17.8 F	3.87 G	1.95 I	6.52 D	4.15 BC	100 C	31.0 EF	10.3 GH
Book - 22	4	20.8 G	4.18 H	1.94 I	6.02 D	3.17 AB	100 C	31.9 F	9.9 FG
Tarpaper-6	4	24.8 H	4.21 H	1.21 GH	5.73 D	4.50 B-D	100 C	36.9 G	11.1 GH
Tube - 40	4	20.3 G	4.34 H	2.54 IJ	7.10 D	2.72 A	95 BC	30.2 EF	10.1 FG
Book - 45	4	24.0 H	4.62 I	2.82 J	7.26 D	2.74 A	100 C	36.8 G	11.5 H
BR 3-0		28.6 I	3.90 C	1.09 FG	3.49 BC	3.20 AB	90 AB	34.1 E-G	7.3 CD

(continued)

TABLE 14. (continued)

Container	Sludge	1981 (Greenhouse) Height	Stem Diameter	Root Dry Wt.	Shoot Dry Wt.	Shoot / Root	1982 (Field) Survival	Height	Stem Diameter
	%(v/v)	(cm)	(mm)	(g)	(g)		(%)	(cm)	(mm)
					WHITE PINE				
Tube - 10	0	6.0 BC	2.64 D	0.77 C-E	1.84 CD	2.54 CD	100 C	23.5 A-D	5.8 BC
Book - 11	0	6.1 BC	2.31 BC	0.53 C	1.62 CD	3.18 DE	100 C	22.3 A-C	5.6 B
Tarpaper-8	0	6.4 D	2.00 A	0.20 A	0.74 A	4.06 EF	95 BC	20.5 AB	4.3 A
Styro. - 21	0	5.4 A	2.62 D	0.59 CD	2.13 DE	3.88 D-F	100 C	21.2 AB	5.6 B
Book - 22	0	6.6 C-E	2.47 CD	0.49 BC	1.60 CD	3.42 DE	95 BC	24.4 B-E	6.3 B
Tarpaper-6	0	5.9 B	2.22 B	0.37 B	0.93 AB	2.66 CD	95 BC	19.8 A	4.3 A
Tube - 40	0	6.5 CD	2.88 E	0.88 D-F	2.13 DE	2.73 C-E	85 BC	26.4 C-F	6.7 B-D
Book - 45	0	6.6 C-E	3.10 E	0.96 E-G	2.20 DE	2.47 C	100 C	27.6 D-G	7.5 DE
Tube - 10	4	6.4 B-D	3.14 E	1.31 FG	2.51 E	2.08 BC	100 C	29.1 FG	7.3 DE
Book - 11	4	6.5 C-E	3.00 E	1.16 E-G	2.59 E	2.68 C-E	100 C	26.2 C-F	6.9 CD
Tarpaper-8	4	6.5 C-E	2.30 BC	0.36 B	1.35 BC	4.29 F	90 BC	20.3 AB	4.7 A
Styro. - 21	4	6.1 B-D	3.52 F	2.22 H	4.75 G	2.17 BC	100 C	31.5 GH	8.3 EF
Book - 22	4	6.7 D-F	3.61 G	1.57 G	3.26 F	2.13 BC	95 BC	31.5 GH	8.2 EF
Tarpaper-6	4	7.4 F	3.63 FG	0.81 C-E	3.66 FG	5.02 E	100 C	28.2 E-G	7.3 DE
Tube - 40	4	8.1 G	4.13 H	2.54 H	4.60 G	1.86 B	100 C	37.4 I	10.2 G
Book - 45	4	7.2 EF	3.97 GH	2.68 H	3.98 FG	1.55 A	100 C	35.9 HI	9.2 FG
BR 2-0		14.1 H	3.80 GH	1.07 E-G	1.94 C-E	1.81 B	90 B	35.6 DE	8.3 C
BR 2-1		26.3 I	5.20 I	2.86 H	3.85 FG	1.35 A	65 A	41.9 F	7.5 BC

(continued)

TABLE 14. (continued)

Container	Sludge	1981 (Greenhouse) Height	Stem Dia-meter	Root Dry Wt.	Shoot Dry Wt.	Shoot/Root
	%(v/v)	(cm)	(mm)	(g)	(g)	
				NOBLE FIR		
Tube - 10	0	10.3 B	3.09 C	0.94 BC	2.26 BC	2.52 B
Book - 11	0	10.3 B	3.15 C	0.67 B	1.96 B	2.97 BC
Tarpaper-8	0	8.7 A	2.09 A	0.30 A	0.85 A	3.01 C
Styro. - 21	0	10.1 B	3.52 D	1.21 E	2.94 E	2.77 BC
Book - 22	0	11.6 C	3.53 D	1.42 DE	2.85 CD	2.06 A
Tarpaper-6	0	8.4 A	2.49 B	0.66 B	1.28 A	1.95 A
Tube - 40	0	11.3 C	3.55 D	1.79 EF	3.36 DE	1.96 A
Book - 45	0	12.5 D	3.76 D	1.68 D-F	3.31 DE	2.02 A
Tube - 10	4	12.9 D	3.47 D	1.18 CD	2.76 CD	2.45 B
Book - 11	4	12.5 D	3.11 C	1.36 C-E	2.81 CD	2.41 B
Tarpaper-8	4	10.3 B	2.36 B	0.34 A	1.07 A	3.21 C
Styro. - 21	4	15.1 E	4.21 E	2.14 FG	5.60 G	2.69 BC
Book - 22	4	16.5 F	4.32 E	2.22 FG	4.08 EF	1.91 A
Tarpaper-6	4	14.4 E	3.83 D	1.27 C-E	3.50 DE	2.94 BC
Tube - 40	4	15.7 EF	4.25 E	3.33 H	5.58 G	1.69 A
Book - 45	4	15.7 EF	4.69 F	2.87 GH	5.02 FG	1.89 A

(continued)

TABLE 14. (continued)

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* Means followed by the same letter are not different at the 0.05 level according to a Duncan's Modified LSD Test.

+ 0 = peat-vermiculite alone; 4 = sludge added to medium at 4% (v/v).

‡ Books from Spencer Lemaire, Edmonton, Alta., Can; Styroblocks from Silvaseed Co., Roy, WA; Paper bands from Monarch Mfg., Salida, CO; Tarpaper bands were handmade; Tube - 10 "Conetainers" from Poly-cast Plastics, Beverton, OR.; Tube - 40 "Deepot" from J.M. McConkey Co., Sumner, WA.

TABLE 15. GROWTH OF FOUR GREENHOUSE-GROWN CONIFEROUS SPECIES IN 11 DIFFERENT CONTAINERS WITH AND WITHOUT 3.5% (V/V) SLUDGE IN 1981

Container	Species							
	Blue Spruce		Douglas-Fir		Noble Fir		White Pine	
	Height	Stem Diameter	Height	Stem Diameter	Height	Stem Diameter	Height	Stem Diameter
	mm							
	SLUDGE ADDED							
Styro. - 7	191 A*	2.5 A	194 B-D	2.7 AB	-	-	136 A	2.1 A
Tube - 10	182 A	2.3 A	152 A	2.3 A	121 A	2.5 A	140 AB	2.1 A
Book - 11	228 BC	2.7 AB	193 B-D	2.5 AB	152 BD	2.9 A-D	157 C-E	2.2 AB
Styro. - 21	236 CD	3.4 C-E	160 AB	2.9 BC	143 A-C	3.6 E-H	155 B-E	2.4 BC
Book - 22	259 C-F	3.4 C-E	279 IJ	3.5 D	171 C-E	3.5 D-H	189 G-H	3.0 E-G
Band - 7	199 AB	2.6 AB	185 C-E	2.6 AB	154 B-D	2.8 AB	138 A	2.3 AB
Band - 8	197 A	2.4 A	208 C-E	2.5 AB	157 B-D	2.8 A-C	153 A-D	2.2 AB
Tube - 40	186 A	2.9 BC	215 C-E	3.3 CD	131 AB	3.5 C-G	142 A-C	2.1 A
Book - 45	278 E-G	3.8 EF	276 H-J	3.9 EF	179 D-F	4.1 H-K	193 GH	3.1 FG
Band - 5	282 E-G	3.7 D-F	233 D-G	3.4 D	202 E-H	4.2 I-K	188 GH	2.7 DE
Band - 6	250 C-E	3.2 C	246 EF	3.3 CD	169 C-E	3.7 E-I	182 F-H	2.7 CD

(continued)

TABLE 15. (continued)

Container	Species							
	Blue Spruce		Douglas-Fir		Noble Fir		White Pine	
	Height	Stem Dia-meter	Height	Stem Dia-meter	Height	Stem Dia-meter	Height	Stem Dia-meter
	mm							
	NO SLUDGE							
Styro. - 7	235 CD	3.3 CD	235 D-G	3.2 CD	-	-	154 B-D	2.6 CD
Tube - 10	250 C-E	3.0 BC	226 D-F	2.9 BC	156 B-D	2.9 A-C	170 EF	2.8 D-F
Book - 11	265 D-F	3.3 C	245 E-H	3.3 CD	186 D-G	3.3 B-F	181 F-H	2.8 DE
Styro. - 21	309 GH	4.3 GH	270 GH	4.1 FG	194 E-H	4.3 I-K	192 GH	3.5 H
Book - 22	277 E-G	3.9 FG	329 KL	4.1 E-G	169 C-E	3.5 D-H	193 GH	3.1 E-G
Band - 7	292 F-H	3.8 EF	287 IJ	3.7 DE	208 F-H	3.7 E-I	179 FG	2.9 E-G
Band - 8	235 CD	2.9 BC	263 F-I	3.3 CD	169 C-E	3.0 A-E	166 D-F	2.6 CD
Tube - 40	275 EF	4.3 GH	307 I-K	4.4 G	185 D-G	4.1 G-K	194 GH	3.5 H
Book - 45	322 H	4.4 H	347 L	4.4 G	216 GH	4.4 K	198 H	3.5 H
Band - 5	312 GH	4.3 GH	314 J-L	4.1 FG	221 H	4.3 I-K	194 GH	3.0 E-G
Band - 6	291 F-H	3.8 EF	269 G-I	3.7 DE	184 D-G	3.8 F-J	190 GH	3.2 GH

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* Means followed by the same letter are not different at the 0.05 level according to a Duncan's Modified LSD Test.

TABLE 16. RELATIONSHIP OF CAVITY DENSITY, VOLUME, DEPTH, AND SURFACE AREA TO TREE HEIGHT, STEM DIAMETER, AND WEIGHT OF FOUR CONIFERS GROWN IN CONTAINERS IN A SLUDGE-AMENDED MEDIUM IN THE GREENHOUSE

Container Variable	Adjusted R^2 (%)							
	1980 Height				Root Wt. 1980			
	BS+	DF	NF	WP	BS	DF	NF	WP
Density	44	36	86**	4	62*	86**	81**	75**
Volume	67*++	65*	17	60*	23	32	24	10
Depth	0	6	-16	48	-12	-14	-14	-17
Surface Area	49	38	26	11	23	49	35	33
	1980 Diameter				Shoot Wt. 1980			
Density	75**	83**	91**	84**	84**	93**	95**	89**
Volume	54**	53*	24	40	39	50	16	22
Depth	- 4	- 4	-15	- 7	-16	-11	-17	16
Surface Area	52*	50*	37	37	68*	74**	48	54*

(continued)

TABLE 16. (continued)

Container Variable	Adjusted R^2							
	1981 Height				1981 Diameter			
	BS	DF	NF	WP	BS	DF	NF	WP
Density	66**	49*	13	91**	77**	74**	72**	83**
Volume	41*	53*	25	51*	47*	56**	49*	40
Depth	- 4	-10	- 8	5	10	-11	-13	-11
Surface Area	76**	49*	56**	- 8	75**	69**	88**	53

+ BS = blue spruce, DF = Douglas-fir, NF = noble fir, WP = white pine.

++ *, ** Indicate significance at the 0.05 and 0.01 levels, respectively.

TABLE 17. EFFECTS OF VARIOUS FERTILIZER AND SLUDGE TREATMENTS ON THE GROWTH AND FOLIAR ELEMENT CONTENT OF BLUE SPRUCE AND DOUGLAS-FIR SEEDLINGS GROWN IN CONTAINERS+

Treatment	Height	Diameter	Root Dry Wt.	Shoot Dry Wt.
	(cm)	(mm)	(g)	(g)
		BLUE SPRUCE		
1 ‡	13.8 A-C*	1.6 A-C	0.13 A	0.57 A
2	12.9 AB	1.5 AB	0.09 A	0.49 A
3	14.7 BC	1.8 BC	0.14 A	0.70 A
4	15.2 C	1.9 CD	0.15 A	0.72 A
5	15.5 C	1.9 CD	0.16 A	0.79 AB
6	19.6 D	2.2 DE	0.26 A	1.15 B
7	12.5 A	1.4 A	0.10 A	0.46 A
8	22.5 E	2.5 EF	0.31 B	1.59 C
9	23.2 E	2.6 F	0.34 B	1.67 C
10	22.5 E	2.5 EF	0.32 B	1.55 C
11	23.1 E	2.5 EF	0.32 B	1.59 C
		DOUGLAS-FIR		
1	13.0 A	1.9 A	0.20 A	0.65 A
2	14.1 AB	2.1 AB	0.20 A	0.88 AB
3	15.3 B	2.2 AB	0.28 AB	1.09 BC
4	15.3 B	2.1 AB	0.26 AB	1.03 A-C
5	15.7 B	2.2 AB	0.28 AB	1.06 A-C
6	19.0 C	2.4 B	0.34 BC	1.33 C
7	13.0 A	2.0 A	0.22 A	0.72 AB
8	24.6 D	2.8 C	0.47 D	1.98 D
9	24.1 D	2.6 BC	0.45 D	1.90 D
10	23.6 D	2.7 BC	0.44 CD	1.89 D
11	24.3 D	2.7 BC	0.41 CD	1.83 D

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* Means followed by the same letter do not differ significantly at the 0.05 level.

+ Ray Leach super cell "conetainers" were the only type used.

(continued)

TABLE 17. (continued)

Treatment	P	K	Mg	Ca	Fe	Mn	Cu	Zn
	(Percent Dry Wt)				(μg/g)			
				BLUE SPRUCE				
1	0.23 B	1.28 D	0.37 B	1.02 BC	66 CD	241 D	1.5 A	53 B
2	0.26 B	1.20 CD	0.38 B	1.15 DE	73 DE	224 D	1.4 A	55 B
3	0.23 B	1.12 C	0.36 B	1.10 CE	72 DE	206 CD	1.3 A	42 A
4	0.25 B	1.15 CD	0.37 B	1.06 CD	65 CD	221 D	1.4 A	41 A
5	0.24 B	1.14 CD	0.37 B	1.08 CD	76 E	212 CD	1.2 A	46 AB
6	0.20 B	0.86 A	0.29 A	0.99 BC	53 B	54 A	1.4 A	40 A
7	0.23 B	1.07 BC	0.42 C	1.23 E	63 C	221 D	1.3 A	40 A
8	0.17 A	0.82 A	0.29 A	0.91 AB	44 A	149 B	2.3 B	49 AB
9	0.17 A	0.80 A	0.28 A	0.92 AB	43 A	113 B	2.6 BC	68 C
10	0.18 A	0.97 AB	0.28 A	0.84 A	43 A	161 BC	2.9 C	40 A
11	0.18 A	0.85 A	0.29 A	0.82 A	42 A	212 CD	3.5 D	53 B
				DOUGLAS-FIR				
1	0.49 B	0.83 AB	0.31 BC	0.62 AB	53 A	186 C	1.5 A	43 CD
2	0.56 BC	1.09 C	0.36 D	0.69 BC	49 A	164 C	1.7 AB	54 E
3	0.52 BC	0.88 AB	0.33 C	0.67 A-C	53 A	176 C	1.7 AB	43 B-D
4	0.59 C	0.87 AB	0.30 C	0.60 A	46 A	184 C	1.7 AB	40 A-D
5	0.55 BC	0.82 A	0.32 BC	0.61 AB	46 A	173 C	1.6 AB	41 A-D
6	0.39 A	0.80 A	0.27 A	0.69 BC	51 A	47 A	2.0 B	34 AB
7	0.53 BC	0.85 AB	0.33 C	0.67 A-C	51 A	173 C	1.5 A	33 A
8	0.33 A	0.75 A	0.27 A	0.65 A-C	50 A	104 B	2.7 C	42 B-D
9	0.37 A	0.80 A	0.28 A	0.64 A-C	43 A	93 B	3.3 D	68 F
10	0.34 A	0.83 A	0.27 A	0.62 AB	50 A	124 B	3.1 D	36 A-C
11	0.33 A	0.74 A	0.29 AB	0.71 C	47 A	177 C	3.7 E	43 CD

(continued)

TABLE 17. (continued)

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‡ Treatments were added to a peat medium; medium plus treatment pH is listed.

1. None 1.0 g Hydrated dolomitic lime, pH 4.8
2. 4.0 g Osmocote 18-6-12 + 1.0 g Hydrated dolomitic lime, pH 4.6
3. 2.0 g " " " " + " " " ", pH 4.5
4. 4.0 g Osmocote 14-14-14 + " " " ", pH 4.7
5. 2.0 g Osmocote " " " + " " " ", pH 4.7
6. 7.2 g Lakewood L/F sludge + 0 " " ", pH 6.4
7. 1.0 g Triple Super Phosphate (45% P) + 1.3 Hydrated dolomitic lime, pH 5.3
8. 8.6 g North Olmsted Zimpro Sludge + 1.0 " " ", pH 5.5
9. 6.6 g Milorganite activated sludge + 1.0 " " ", pH 4.9
10. 11.4 g Greenhouse anaerobic sludge + 0.7 " " ", pH 5.3
11. 22.1 g " " " + 0.4 " " ", pH 5.2

TABLE 18. ELEVEN AMENDMENTS TO A SINGLE PEAT MEDIUM AND THEIR EFFECTS ON GROWTH MEDIUM pH

Treatment Number	Amendment		Hydrated Dolomitic Lime	Final pH
	(g/l)			
1	None		1.0	4.8 AB
2	4.0	g Osmocote 18-6-12*	1.0	4.6 A
3	2.0	g Osmocote "	1.0	4.5 A
4	4.0	g Osmocote 14-14-14	1.0	4.7 A
5	2.0	g Osmocote "	1.0	4.7 A
6	7.2	g Lakewood L/F sludge	0.0	6.4 E
7	1.0	g TSP+	1.3	5.3 B-D
8	8.6	g N.O. Zimpro sludge	1.0	5.5 D
9	6.6	g M. activated sludge	1.0	4.9 A-C
10	11.4	g GH anaerobic sludge	0.7	5.3 CD
11	22.1	g " " "	0.4	5.2 B-D

* Osmocote added at full (4 g) or one half (2 g) the recommended rate.

+ Triple super phosphate (45 % P).

TABLE 19. GROWTH OF BLUE SPRUCE SEEDLINGS IN A PEAT-VERMICULITE MEDIUM AMENDED WITH EITHER COPPER, MICRONUTRIENT SUPPLEMENTS, SEWAGE SLUDGE, OR CHARCOAL

Treatment		Dolomitic Lime	Height	Diameter	Root Dry Wt.	Shoot Dry Wt.
(g/l)			(cm)	(mm)	(g)	(g)
None		1.00	20.7 BC*	2.4 C-E	0.31 B-D	1.15 B-E
0.01	Copper	1.00	21.5 BC	2.3 B-D	0.31 B-D	1.09 B-E
0.50	fritted micronutrients+	1.00	22.5 C	2.4 C-E	0.35 B-E	1.25 D E
0.25	"	1.00	20.9 BC	2.3 B-E	0.32 B-E	1.16 B-E
0.10	"	1.00	21.9 BC	2.4 B-E	0.36 C-E	1.22 C-E
0.50	soluble micronutrients	1.00	20.8 BC	2.4 C-E	0.34 B-E	1.15 B-E
0.25	"	1.00	21.6 BC	2.6 E	0.35 B-E	1.19 C-E
0.10	"	1.00	20.3 BC	2.5 DE	0.33 B-E	1.13 B-E
2.00	Osmocote 14-14-14	1.00	21.4 BC	2.4 C-E	0.31 B-D	1.21 C-E
1.00	"	1.00	20.2 BC	2.2 B-D	0.29 BC	1.06 B-E
11.40	Wooster sludge	0.68	20.0 BC	2.3 B-D	0.30 B-D	1.14 B-E
7.20	lime-ferric sludge	0.00	19.8 B	2.2 AB	0.29 B	0.97 AB
8.64	fine North Olmsted sludge	1.00	21.8 BC	2.3 B-E	0.34 B-E	1.15 B-E
8.64	coarse "	1.00	19.9 B	2.3 B-E	0.31 B-D	1.05 B-D
6.64	fine Milorganite	1.00	17.6 A	2.0 A	0.22 A	0.83 A
6.64	coarse "	1.00	20.8 BC	2.3 B-E	0.27 AB	1.07 B-E
5.70	fine Lakewood sludge	0.84	22.4 C	2.5 DE	0.36 DE	1.25 DE
11.40	fine "	0.68	22.2 BC	2.4 C-E	0.36 DE	1.23 C-E
11.40	coarse "	0.68	21.7 BC	2.5 DE	0.38 E	1.27 E
0.2	fine charcoal	1.00	20.8 BC	2.4 B-E	0.35 B-E	1.15 B-E
1.0	"	1.00	20.3 BC	2.4 C-E	0.31 B-E	1.15 B-E
5.0	"	1.00	21.8 BC	2.4 B-E	0.33 B-E	1.19 C-E
1.0	coarse charcoal	1.00	21.1 BC	2.2 A-C	0.29 B	1.04 BC
5.0	"	1.00	20.6 BC	2.3 B-E	0.33 B-E	1.12 B-E

* Means followed by the same letter are not different at the 0.05 level according to a Duncan's Modified LSD Test.

+ Sequestrene (NaFe), $H_3 BO_4$, $MnSO_4$, $Zn SO_4$.

TABLE 20. GROWTH AND COPPER CONCENTRATIONS OF DOUGLAS-FIR SEEDLINGS GROWN 5 MONTHS FROM SEED IN CONTAINERS+ IN A PEAT-VERMICULITE MEDIUM AMENDED WITH DIFFERENT AMOUNTS OF Cu

Cu (µg/g)	Height (mm)	Diameter (mm)	Root Dry Wt. (gm)	Shoot Dry Wt. (gm)	S:R (w/w)	Shoot Cu (µg/g)
0	171 A*	19.7 A	1.57 A	5.15 A	3.27 A	3.7 A
2	186 B	20.4 AB	1.74 A	5.56 AB	3.20 A	4.7 B
5	192 B	21.1 B	1.66 A	5.68 AB	3.42 A	5.3 B
10	193 B	20.8 AB	1.69 A	5.68 AB	3.42 A	6.5 C
20	192 B	20.8 AB	1.67 A	5.77 B	3.43 A	13.3 D
50	190 B	21.1 B	1.74 A	5.87 B	3.37 A	14.9 D
100	191 B	20.4 AB	1.68 A	5.80 B	3.45 A	20.3 E

* Means followed by the same letter do not differ at the 5% level by the Duncan's Modified LSD Test.

+ Ray Leach super cell "conetainers", Beverton, OR.

TABLE 21. GROWTH AND FOLIAR COPPER CONCENTRATIONS OF FOUR CONIFERS GROWN 5 MONTHS IN CONTAINERS‡ IN A PEAT-VERMICULITE MEDIUM AMENDED WITH FERTILIZER COPPER OR SLUDGE+

Species	Cu Tmt. (µg/g)	Height (mm)	Diameter (mm)	Root Wt. (g)	Shoot Wt. (g)	Shoot/Root (w/w)	Foliar Cu (µg/g)
Blue Spruce	.00	148 B*	2.1 AB	0.46 A	0.80 AB	1.78 B	2.4 A
	.01	138 AB	2.0 A	0.49 A	0.67 A	1.42 A	3.3 BC
	.04	126 A	2.0 A	0.59 A	0.66 A	1.40 A	3.6 B
	.16	158 B	2.2 B	0.52 A	0.89 B	1.74 B	3.7 B
	.64	142 AB	2.1 AB	0.53 A	0.81 AB	1.53 A	3.6 B
	S+	192 C	2.5 C	0.63 A	1.29 C	2.13 C	3.7 B
Douglas-fir	.00	128 A	1.9 A	0.27 A	0.62 A	2.98 B	2.0 A
	.01	136 A	2.2 B	0.38 B	0.74 AB	1.86 A	2.1 A
	.04	136 A	2.1 AB	0.36 B	0.73 AB	2.13 A	2.6 B
	.16	155 B	2.4 B	0.44 BC	0.91 B	2.01 A	3.2 C
	.64	164 B	2.3 B	0.43 BC	0.88 B	2.01 A	3.6 C
	S	184 C	2.7 C	0.51 C	1.17 C	2.26 A	3.1 C
Noble Fir	.00	91 AB	2.0 A	0.30 A	0.65 A	2.18 C	2.2 A
	.01	93 B	2.1 AB	0.48 B	0.61 A	1.48 A	3.3 AB
	.04	89 A	2.0 A	0.35 A	0.55 A	1.63 AB	4.0 B
	.16	99 B	2.1 AB	0.37 A	0.63 A	1.69 AB	5.7 CD
	.64	96 B	2.1 AB	0.37 A	0.70 A	1.85 B	7.7 D
	S	119 C	2.3 B	0.43 B	0.96 B	2.34 C	5.4 C
Eastern White Pine	.00	90 AB	2.4 AB	0.81 A	1.28 C	1.61 B	3.3 A
	.01	84 A	2.3 A	0.90 A	1.03 AB	1.24 A	3.9 AB
	.04	84 A	2.3 A	0.89 A	0.96 A	1.14 A	4.6 B
	.16	87 A	2.4 AB	0.74 A	1.10 B	1.55 B	5.9 C
	.64	88 A	2.5 B	1.06 B	1.10 B	1.12 A	6.9 D
	S	93 B	2.7 C	0.84 A	1.55 D	1.87 C	5.3 AB

* Means followed by the same letter are not different at the 5% level by the Duncan's Modified LSD Test.

+ 2% (v/v) Lakewood, Ohio anaerobically digested sewage sludge, no fertilizer Cu.

‡ Ray Leach super cell "conetainers", Beverton, OR.

TABLE 22. GROWTH AND COPPER CONCENTRATIONS OF FOUR CONIFERS GROWN 6 MONTHS IN CONTAINERS‡ IN A 70:30 (V/V BARK-VERMICULITE MEDIUM AMENDED WITH DIFFERENT AMOUNTS OF FERTILIZER COPPER OR SLUDGE

Species	Treatment Cu (µg/g)	Root Dry Weight (g)	Shoot Dry Weight (g)	Shoot/Root	Foliar Cu (µg/g)
Blue Spruce	.00	.10 A*	0.30 AB	3.68 C	1.5 A
	.01	.09 A	0.24 A	3.30 BC	1.8 A
	.04	.20 B	0.48 BC	2.55 AB	1.3 A
	.16	.38 C	0.74 D	2.19 A	1.4 A
	.64	.33 C	0.69 CD	2.22 A	2.0 A
	S+	.53 D	1.10 E	2.20 A	1.8 A
Douglas-fir	.00	.31 A	0.46 A	1.49 AB	1.7 A
	.01	.28 A	0.39 A	1.40 A	1.6 A
	.04	.29 A	0.51 A	1.75 BC	1.7 A
	.16	.42 B	0.85 B	1.48 CD	2.0 A
	.64	.47 BC	1.01 BC	2.13 D	2.1 A
	S	.56 C	1.21 C	2.14 D	1.8 A

(continued)

TABLE 22. (continued)

Species	Treatment Cu (µg/g)	Root Dry Weight (g)	Shoot Dry Weight (g)	Shoot/Root	Foliar Cu (µg/g)
Noble Fir	.00	.23 A	0.53 A	2.35 B	2.3 AB
	.01	.22 A	0.53 A	2.35 B	2.2 A
	.04	.31 AB	0.68 AB	2.21 AB	2.4 AB
	.16	.45 CD	0.92 BC	2.05 A	2.7 B
	.64	.35 BC	0.76 AB	2.13 AB	4.2 C
	S	.55 D	1.06 C	2.08 AB	2.6 AB
Eastern White Pine	.00	.30 A	0.48 A	1.66 B	2.0 A
	.01	.39 AB	0.55 A	1.49 AB	1.8 A
	.04	.45 B	0.65 AB	1.46 AB	1.9 A
	.16	.63 C	0.83 B	1.34 A	2.4 AB
	.64	.81 D	1.27 C	1.60 B	2.6 B
	S	.54 BC	0.84 B	1.66 B	1.8 A

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* Means followed by the same letter are not different at the 5% level by the Duncan's Modified LSD Test.

+ 2% (v/v) Lakewood, Ohio anaerobically digested sewage sludge, no fertilizer Cu.

‡ Ray Leach super cell "conetainers", Beverton, OR.

TABLE 23. GROWTH AND COPPER CONCENTRATIONS OF DOUGLAS-FIR SEEDLINGS GROWN 4 MONTHS IN CONTAINERS[§] IN VARIOUS COPPER AND NITROGEN TREATMENTS IN A PEAT-VERMICULITE CONTAINER MEDIUM

Cu	N[*]	Height	Diameter	Shoot Wt.	Root Wt.	Foliar Cu
(µg/g)		(mm)	(mm)	(g)	(g)	(µg/g)
0	25	133 AB[+]	1.3 A	2.54 A	0.61 A	3.7 B
0	100	134 B	1.4 A	2.80 A	0.67 A	2.6 A
0	250	125 A	1.6 BC	2.51 A	0.64 A	2.7 A
10	25	177 C	1.6 BC	4.00 B	0.99 B	10.1 C
10	100	169 C	1.6 BC	4.10 B	1.01 B	10.2 C
10	250	180 C	1.8 C	4.44 C	0.97 B	9.9 C
100	25	173 C	1.5 A-C	3.79 B	0.91 B	53.6 D
100	100	180 C	1.7 B	4.14 B	0.96 B	65.8 D
100	250	191 D	1.7 B	4.48 C	0.99 B	58.1 D
0	-[‡]	131 A	1.4 A	2.62 A	0.64 A	3.0 A
10	-	175 B	1.7 B	4.18 B	0.99 B	10.1 C
100	-	181 B	1.6 BC	4.14 B	0.95 B	59.2 D
-	25	161 C	1.4 A	3.44 A	0.84 AB	22.4 CD
-	100	161 C	1.6 BC	3.68 AB	0.88 AB	26.2 CD
-	250	165 C	1.7 B	3.81 B	0.87 AB	23.6 CD

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[*] Copper applied as a single drench and expressed as mg Cu per liter of medium. Nitrogen expressed as N concentration in the semiweekly fertilizer treatment.

[+] Means followed by the same letter are not different at the 5% level by the Duncan's Modified LSD Test.

[‡] Averages for the copper and nitrogen factors, respectively.

[§] Ray Leach super cell "conetainers", Beverton, OR.

TABLE 24. SURVIVAL OF GREENHOUSE-GROWN DOUGLAS-FIR SEEDLINGS IN SOIL TREATED WITH 1 OR 5% (V/V) SLUDGE FROM FOUR SOURCES, OR WITH 250 ppm UREA-N

Treatment		Survival (%)
None		93 E*
250 ppm urea-N		84 DE
LW-L/F	1%+	60 BC
LW-L/F	5%	49 B
M-Act	1%	73 CD
M-Act	5%	9 A
NO-Z	1%	93 E
NO-Z	5%	89 DE
Wo-An	1%	82 DE
Wo-An	5%	87 DE

* Means followed by the same letter are notdifferent at the 0.05 level by Duncan's Modified LSD Test.

+ Sludge Sources: Lakewood, OH, lime-ferric treatment; Milwaukee, WI, activated sludge ("Milorganite"); North Olmsted, OH, Zimpro process; Wooster, OH, anaerobically digested.

TABLE 25. GROWTH AND ELEMENT CONCENTRATIONS OF GREENHOUSE-GROWN SWEETGUM SEEDLINGS GROWN 5 MONTHS IN A SAND-SOIL-PEAT MIX AS AFFECTED BY MYCORRHIZAL INOCULATION, PHOSPHORUS, COPPER, ZINC, AND SLUDGE

	P	Cu	Zn	Sludge %	Height	Stem Diameter Growth	
						Total	Last 7 Wks
MR*	(µg/g)			(v/v)	(mm)	(mm)	(mm)
0	0	0	0	0	37 A+	1.1 A	0.0 A
0	0	5	0	0	34 A	1.0 A	0.0 A
0	0	0	8	0	35 A	1.1 A	0.0 A
0	0	5	8	0	37 A	1.0 A	0.0 A
0	50	0	0	0	73 BC	2.2 BC	0.5 B
0	50	5	0	0	69 BC	2.2 BC	0.5 B
0	50	0	8	0	68 B	2.0 B	0.5 B
0	50	5	8	0	91 C	2.2 BC	0.5 B
0	500	0	0	0	220 E	4.3 E	1.6 D
0	500	5	0	0	283 F	4.8 F	2.2 E
0	500	0	8	0	268 F	4.3 E	2.0 E
0	500	5	8	0	293 F	5.0 G	2.2 E
+	0	0	0	0	170 D	4.0 DE	1.2 C
+	0	5	0	0	151 D	3.8 D	1.0 C
+	0	0	8	0	136 D	3.7 D	1.0 C
+	0	5	8	0	143 D	3.7 D	1.0 C
+	50	0	0	0	304 F	5.9 H	2.2 E
+	50	5	0	0	282 F	5.8 H	2.2 E
+	50	0	8	0	323 F	5.7 H	2.2 E
+	50	5	8	0	293 F	5.8 H	2.2 E
+	500	0	0	0	318 F	6.2 H	2.1 E
+	500	5	0	0	310 F	6.2 H	2.2 E
+	500	0	8	0	305 F	6.1 H	2.2 E
+	500	5	8	0	321 F	6.0 H	2.1 E
0	0	0	0	2	108 CD	1.9 B	0.5 B
+	0	0	0	2	238 EF	4.2 DE	1.5 D

(continued)

TABLE 25. (continued)

MR	Root Dry Wt. (g)	Shoot Dry Wt. (g)	Total Dry Wt. (g)	Foliar P (%)	Foliar Cu (µg/g)	Foliar Zn (µg/g)
0	0.06 A	0.03 A	0.09 A	-‡	-	-
0	0.05 A	0.03 A	0.08 A	-	-	-
0	0.06 A	0.03 A	0.09 A	-	-	-
0	0.06 A	0.02 A	0.08 A	-	-	-
0	0.43 C	0.29 BC	0.72 BC	0.07 BC	5.3 F	80 E
0	0.44 C	0.26 BC	0.70 BC	0.06 B	7.6 HI	70 E
0	0.31 B	0.23 B	0.55 B	0.07 BC	6.7 G	73 E
0	0.44 C	0.33 C	0.76 C	0.07 BC	7.6 G-I	80 E
0	2.12 DE	3.16 E	5.28 EF	0.23 E-G	2.3 AB	45 AB
0	2.30 EF	4.37 EF	6.65 EF	0.21 D-F	2.6 A-C	42 A
0	1.58 D	3.63 E	5.21 E	0.18 D	2.0 A	45 AB
0	2.64 F	4.36 EF	7.00 F	0.19 DE	2.4 AB	46 AB
+	1.67 DE	1.34 D	3.02 D	0.06 B	6.6 G	69 DE
+	1.50 D	1.34 D	2.84 D	0.05 A	8.5 I	70 E
+	1.48 D	1.25 D	2.72 D	0.05 A	7.4 GH	75 E
+	1.47 D	1.24 D	2.70 D	0.05 A	7.2 GH	83 E
+	4.66 G	5.91 FG	10.61 G	0.08 BC	2.8 A-C	44 AB
+	4.40 G	5.09 FG	9.49 G	0.07 BC	3.7 CD	46 AB
+	3.90 G	5.87 FG	9.78 G	0.08 BC	2.3 AB	54 BC
+	4.15 G	5.30 FG	9.44 G	0.08 BC	4.3 EF	53 BC
+	4.88 G	7.69 G	11.57 G	0.27 GH	3.3 B-D	52 BC
+	5.29 G	6.12 FG	11.40 G	0.24 FG	4.1 D-F	51 A-C
+	4.66 G	5.94 FG	10.60 G	0.27 H	3.2 B-D	65 D
+	4.74 G	6.30 FG	11.06 G	0.33 H	4.4 EF	60 CD
0	0.27 B	0.42 BC	0.70 BC	0.09 C	8.2 I	84 E
+	1.92 DE	2.91 E	4.83 E	0.09 C	7.5 G-I	78 E

* MR = mycorrhizal inoculum Glomus fasciculatus pot culture soil at 2% total volume.

+ Values followed by the same letter do not differ significantly at the 0.05 level according to Duncan's Modified LSD Test.

‡ Insufficient tissue for complete analysis - values of combined tissue: P - .04%; Cu - 8.1 ppm; Zn - 91 ppm.

TABLE 26. QUANTITIES OF ELEMENTS ADDED TO SOIL IN FOUR SLUDGES WHEN SLUDGES WERE APPLIED IN AMOUNTS LARGE ENOUGH TO ADD 100 µg/g P

Element Added	Element Additions			
	Zim-C*	Zim-NO	L/F-LW	AS-M
	(µg/g)			
Sludge	3880.0	1680.0	4150.0	8330.0
P	100.0	100.0	100.0	100.0
K	5.0	1.7	5.8	37.5
Ca	198.1	72.1	717.5	5.8
Mg	15.1	5.8	19.9	2.8
Na	1.9	0.8	3.3	9.0
Fe	92.6	29.1	201.7	315.7
Al	31.8	115.7	40.7	57.5
Zn	25.1	1.7	24.3	7.7
Cu	2.4	1.3	1.4	3.1
Mn	2.0	2.4	3.8	1.4
Cr	8.2	0.2	1.2	47.6
B	0.2	0.1	0.4	0.8
Pb	0.6	0.3	0.6	3.8
Cd	0.4	0.1	0.1	1.0
Ni	1.5	0.1	0.2	0.5
Hg	0.2	0.2	0.2	0.5
N	75.0	38.0	79.0	560.0

* Zimpro treatment, Canton, OH; Zimpro treatment, North Olmsted, OH; Lime-ferric treatment, Lakewood, OH; Activated sludge, Milwaukee, WI (Milorganite).

TABLE 27. SOIL NH_4^+, NO_2^-, AND pH VALUES VARIOUS TIMES AFTER THE ADDITION OF SLUDGE PROVIDING AN EQUIVALENT OF 100 mg P/kg SOIL

	NH_4^+ - N				NO_2^- - N				pH			
	day				day				day			
Sludge[+]	2	5	12	27	2	5	12	27	2	5	12	27
	(μg/g)											
None	143 D[‡]	129 CD	168 E	84 B	.05 AB	.08 BC	.31 D	.04 AB	6.7 A	6.9 A	6.5 A	6.0 A
Zim-C	126 C	124 C	137 CD	67 B	.09 BC	.79 E	.47 D	.08 BC	6.7 A	6.9 A	6.5 A	6.1 A
Zim-NO	136 CD	137 CD	167 E	61 B	.03 A	.07 BC	.76 E	.08 BC	6.7 A	6.9 A	6.5 A	5.9 A
L/F-LW	131 C	139 CD	171 E	13 A	.31 D	.17 CD	9.74 F	.16 CD	7.3 B	7.6 C	7.2 C	6.5 B
AS-M	183 E	266 F	371 G	200 E	.15 CD	3.42 F	1.36 E	.15 CD	6.7 A	7.2 B	6.9 B	6.1 A

[+] Zimpro treatment, Canton, OH; Zimpro treatment, N. Olmsted, OH; Lime-ferric treatment, Lakewood, OH; Activated sludge, Milwaukee, WI (Milorganite); or no sludge added.

[‡] Means followed by the same letter do not differ at the 0.05 level by Duncan's Modified LSD Test. NH_4^+ and NO_2^- each analyzed statistically over all days and pH determined for individual sampling periods.

TABLE 28. SHOOT ELEMENT ANALYSES AND DRY WEIGHTS OF SOYBEANS GROWN WITH OR WITHOUT MYCORRHIZAL INOCULUM IN SOIL TREATED WITH VARIOUS SLUDGES AND RATES OF PHOSPHORUS

		First Planting						
		Added	Content	Concentration				
MR*	Sludge⁺	P	P	P	Cu	Zn	Mn	Shoot Wt.
		(µg/g)	(mg)	(%)	(µg/g)			(g)
0	None	30	0.6 A§	0.05 A	4.0 A-D	27 A-F	134 D-I	1.2 AB
0	"	105	0.6 A	0.06 A	3.5 A-C	29 A-H	138 F-I	1.2 AB
0	"	210	3.0 EF	0.10 G-I	4.1 B-D	38 I-K	145 H-K	2.8 G-L
0	"	345	6.0 K-M	0.15 JK	3.6 A-C	37 I-K	177 J-L	3.8 O
0	"	420	10.2 O	0.24 L	3.6 A-C	40 I-L	187 K-M	3.8 O
0	Zim-C	0	0.8 A-C	0.06 A	4.1 B-D	41 J-M	198 LM	1.4 A-E
0	"	60	2.1 B-E	0.08 D-G	4.0 A-D	35 G-J	239 MN	2.4 F-H
0	"	150	3.3 E-G	0.11 HI	4.4 B-F	36 H-J	267 N	2.8 G-K
0	"	270	4.6 G-J	0.15 JK	4.0 A-D	35 G-J	386 O	2.9 G-L
0	Zim-NO	0	0.7 AB	0.06 A-D	3.3 AB	21 A	366 O	1.3 A-D
0	"	60	1.1 A-D	0.08 B-E	3.7 A-D	27 A-F	415 O	1.6 A-E
0	"	150	1.5 A-D	0.08 B-E	2.9 A	30 B-H	412 O	1.9 C-F
0	"	270	3.7 F-H	0.14 J	3.5 A-C	29 A-H	556 P	2.8 G-L
0	L/F-LW	0	0.8 A-C	0.06 AB	3.4 A-C	22 AB	134 D-I	1.3 A-D
0	"	60	0.9 A-D	0.06 A-C	3.9 A-D	24 AB	128 C-I	1.6 A-E
0	"	150	2.4 DE	0.08 B-E	3.9 A-D	26 A-D	134 D-I	2.7 G-K
0	"	270	4.2 F-I	0.11 HI	3.8 A-D	23 AB	150 G-J	3.6 M-O
0	AS-M	0	0.7 AB	0.08 B-E	4.0 A-D	26 A-D	91 AB	1.0 A
0	"	60	1.0 A-C	0.08 B-E	4.4 B-F	25 A-C	111 A-G	1.3 A-D
0	"	150	2.0 A-E	0.09 E-G	4.4 B-F	26 A-D	134 D-I	2.3 FG
0	"	270	4.4 G-I	0.12 I	4.4 B-F	34 F-J	141 F-J	3.6 M-O

(continued)

TABLE 28. (continued)

				First Planting				
		Added	Content	Concentration				
MR	Sludge	P	P	P	Cu	Zn	Mn	Shoot Wt.
		(µg/g)	(mg)	(%)	(µg/g)			(g)
+	None	30	1.4 A-D	0.09 E-H	8.2 J	46 LM	115 A-H	1.7 B-E
+	"	105	5.0 H-K	0.17 K-N	6.8 HI	38 I-K	120 B-I	2.9 G-L
+	"	210	6.4 LM	0.18 M-P	5.5 FG	40 I-L	106 A-F	3.4 L-O
+	"	345	6.0 KL	0.19 N-Q	4.9 D-F	34 E-J	129 D-I	3.3 J-O
+	"	420	8.5 N	0.22 RS	4.3 B-E	32 C-H	120 B-I	3.7 NO
+	Zim-C	0	4.0 F-I	0.16 KL	9.8 K	61 N	105 A-E	2.5 F-I
+	"	60	6.1 K-M	0.18 M-P	6.5 HI	45 K-M	93 AB	3.4 L-O
+	"	150	7.0 LM	0.19 N-Q	6.1 GH	48 M	97 A-C	3.4 L-O
+	"	270	7.4 MN	0.20 PQ	4.4 B-F	41 J-M	100 A-D	3.7 NO
+	Zim-NO	0	4.3 F-I	0.17 K-N	10.3 K	44 K-M	111 H-L	2.8 G-L
+	"	60	6.5 LM	0.21 QR	7.9 J	35 H-J	109 G-L	3.2 J-O
+	"	150	6.6 LM	0.21 QR	6.3 GH	36 H-J	115 A-H	3.4 L-O
+	"	270	6.8 LM	0.18 M-P	4.6 C	33 D-J	123 K-M	3.8 O
+	L/F-LW	0	4.0 F-I	0.15 J-L	8.4 J	39 I-L	101 A-D	2.7 G-J
+	"	60	5.1 I-K	0.16 KL	7.5 I-J	33 D-J	88 A	3.0 H-M
+	"	150	4.7 H-J	0.17 K-N	6.6 HI	27 A-F	95 A-C	3.1 J-N
+	"	270	5.7 J-L	0.17 K-N	5.4 FG	24 AB	91 AB	3.1 J-N
+	AS-M	0	0.8 A-C	0.08 D-G	4.9 D-F	24 AB	139 F-I	1.0 A
+	"	60	1.1 A-D	0.07 A-E	4.3 B-E	28 A-H	133 D-I	1.7 B-E
+	"	150	1.4 A-D	0.08 D-G	4.1 B-D	26 A-D	160 I-L	1.9 D-F
+	"	270	2.1 C-E	0.10 F-I	4.0 A-D	26 A-D	163 I-L	2.0 E-F

* 0 = no mycorrhizal inoculation; + = inoculation with _Glomus fasiculatus._

+ Zimpro treatment, Canton, OH; Zimpro treatment, N. Olmsted, OH; Lime-ferric treatment, Lakewood, OH; Activated sludge, Milwaukee, WI (Milorganite); or no sludge added.

§ Means followed by the same letter do not differ significantly at the 0.05 level from other means in the same column.

TABLE 29. EXTRACTABLE PHOSPHORUS FROM SOIL TREATED WITH SUFFICIENT AMOUNTS OF FOUR SLUDGES TO ADD 100 ug P PER g OF SOIL AT THREE LEVELS OF ADDED Ca $(H_2PO_4)_2$ (CMP) AFTER TWO SUCCESSIVE SOYBEAN PLANTINGS

Sludge Treatment	Extractable P+				
	First Planting			Second Planting	
	µg/g Added Soil P			µg/g Added Soil P	
	150	270	420	270	420
	(µg/g)				
None ‡	58 A*	94 C	159 E	29 A	47 E
Zim-C	60 A	106 CD	-	41 D	-
Zim-NO	58 A	101 CD	-	42 D	-
L/F-LW	81 B	119 D	-	36 C	-
AS-M	65 A	115 D	-	33 B	-

* Means followed by the same letter are not different at the 0.05 level within same planting by a Duncan's Modified LSD Test.

+ Soils extracted with $NaHCO_3$ and Bray #1 extractant after the first and second plantings, respectively.

‡ No sludge added; Zimpro treatment, Canton, OH; Zimpro treatment, N. Olmsted, OH; lime-ferric treatment, Lakewood, OH; activated sludge, Milwaukee, WI (Milorganite).

TABLE 30. EFFECTS OF SLUDGE PARTICLE SIZE ON MYCORRHIZAL SOYBEAN SHOOT DRY WEIGHT AND ELEMENT CONTENTS

Particle Size	Shoot Dry Wt.	P^+	P	Cu	Zn	Mn
(mm)	(g)	(mg)	(%)	(µg/g)		
0 - 2	2.64 A*	5.73 A	0.22 B	6.8 A	61 C	72 A
2 - 10	2.61 A	5.51 A	0.21 B	7.3 A	51 B	72 A
10 - 30	2.79 A	5.76 A	0.21 B	7.4 A	46 B	91 AB
No Sludge	2.89 A	4.93 A	0.17 A	6.8 A	38 A	120 B

* Means followed by the same letter do not differ at the 0.05 level by Duncan's Modified LSD Test.

+ Total phosphorus content of plant.

TABLE 31. NONMYCORRHIZAL AND MYCORRHIZAL SLUDGE TREATMENT AVERAGES FOR SOYBEAN SHOOT DRY WEIGHT, ELEMENTAL ANALYSES, SOIL P, SOIL pH, AND PERCENTAGES OF TOTAL VARIANCE ASSOCIATED WITH MAIN EFFECTS, INTERACTIONS, AND ERROR FOR WEIGHT AND ELEMENT ANALYSES

Treatment			Element Analyses				
Sludge	MR	Shoot Dry Wt.	P‡	P	Cu	Zn	Mn
		(g)	(mg)	(%)	(μg/g)		
None	0	2.25 A-C+	2.58 B	0.09 AB	3.8 A	33 B-D	149 B
"	+	2.84 C-E	4.71 C	0.16 C	6.4 B	40 D	118 AB
Zim-C	0	2.38 B-D	2.68 B	0.10 B	4.1 A	37 CD	273 C
"	+	3.24 E	6.12 D	0.18 D	6.7 B	49 E	99 A
Zim-NO	0	1.87 AB	1.77 AB	0.09 AB	3.4 A	27 AB	437 D
"	+	3.32 E	6.07 D	0.19 D	7.3 B	37 CD	120 AB
L/F-LW	0	2.30 BC	2.08 AB	0.08 A	3.8 A	24 A	137 B
"	+	2.97 DE	4.89 C	0.16 C	7.0 B	31 A-C	94 A
AS-M	0	2.05 AB	2.02 AB	0.09 AB	4.3 A	28 AB	119 AB
"	+	1.67 A	1.36 A	0.08 A	4.3 A	26 AB	149 B

	Partitioned Variance					
Variance Component	Shoot Dry Wt.	P	P	Cu	Zn	Mn
	(g)	(mg)	(%)	(μg/g)		
Sludge	29*	1	1	0	24*	0
Mycorrhizae	4	35*	47*	39*	11	24*
P Level	14*	22*	9*	0	0	0
S X M	1	17*	21*	17*	8*	42*
S X P	11*	2*	2	3*	4	0
M X P	2	5*	6*	20*	14*	16*
S X M X P	10*	2*	4*	0	2	0
Error	29	16	11	20	38	17

* Indicates significance at the 0.05 level by F test with pooled variance in the denominator.

+ Means followed by the same letter are not different at the 0.05 level by Duncan's Modified LSD Test.

‡ Total phosphorus content of plant.

TABLE 32. MINERAL ANALYSIS OF 10-WEEK-OLD BLACK LOCUST SEEDLINGS FROM SLUDGE-AMENDED SOIL

Sludge Source	Sludge Concentration (% by Wt.)	Mineral Concentration in Plant Tissue*			
		%			
		P	K	Ca	Mg
None	0	0.23	0.96	0.88	0.42
Canton	2.5	0.21	0.85	0.82	0.40
	5	0.15	0.81	0.80	0.40
	10	0.18	0.96	0.54	0.31
	25	-+	-	-	-
Cleveland	2.5	0.13	0.70	0.71	0.32
	5	0.16	0.74	0.83	0.40
	10	-	-	-	-
	25	-	-	-	-
Detroit	2.5	0.27	0.68	0.61	0.35
	5	0.14	0.78	0.73	0.27
	10	0.17	0.80	0.64	0.28
	25	-	-	-	-
Mt. Vernon	2.5	-	-	-	-
	5	-	-	-	-
	10	-	-	-	-
	25	0.11	0.83	0.77	0.32

(continued)

TABLE 32. (continued)

Sludge Source	Sludge Concentration (% by Wt.)	Mineral Concentration in Plant Tissue µg/g Fe	Mn	Zn	Cu
None	0	131	146	59	11.1
Canton	2.5	131	113	69	11.3
	5	110	127	65	7.9
	10	71	105	48	11.1
	25	-	-	-	-
Cleveland	2.5	164	178	49	7.5
	5	161	132	57	12.4
	10	-	-	-	-
	25	-	-	-	-
Detroit	2.5	111	140	70	12.8
	5	112	119	44	8.9
	10	87	119	49	7.2
	25	-	-	-	-
Mt. Vernon	2.5	-	-	-	-
	5	-	-	-	-
	10	-	-	-	-
	25	102	133	41	7.3

* Values are averages of plants from 3-6 replicate pots.

+ Dashes indicate data are unavailable because of insufficient plant material for mineral analysis.

TABLE 33. GERMINATION OF *GLOMUS FASCICULATUS* CHLAMYDOSPORES AFTER 21 DAYS IN SLUDGE-AMENDED SOIL*

Sludge Source	Sludge Concentration (% by vol.)	Spore Germination⁺ (%)
None	0	87
Canton	2.5	95
	5	94
	10	95
	25	90
Cleveland	2.5	93
	5	86
	10	93
	25	91
Detroit	2.5	92
	5	88
	10	95
	25	91
Mt. Vernon	2.5	96
	5	94
	10	88
	25	87

* Spores held between two Millipore membranes secured with a photographic slide binder and placed 2.5 cm below the soil surface.

+ Differences between treatment means are not significant ($P = 0.05$).

TABLE 34. EFFECTS OF MT. VERNON SLUDGE IN AGAR ON GERMINATION OF GLOMUS MACROCARPUS CHLAMYDOSPORES

Sludge Concentration (mg sludge/g agar)	Percent of Spores in Each Category* † 0	1	2	3
0	6.4	20.4	8.0	65.2
0.01	8.8	15.2	10.8	65.2
0.1	7.6	21.2	3.6	67.6
1.0	17.2	78.0	3.2	1.6
10.0	21.6	73.2	4.0	1.2
20.0	12.4	84.0	3.6	0.0
100.0	42.0	57.2	0.8	0.0

* Determinations based on 10 replicate plates containing a minimum of 25 spores.

† 0 = ungerminated spores; 1 = single germ tube produced, no hyphal branches; 2 = single germ tube produced, some hyphal branching; 3 = extensive hyphal branching from germ tube.

TABLE 35. EFFECTS OF INCINERATED MT. VERNON SLUDGE IN AGAR ON GERMINATION OF GLOMUS MACROCARPUS CHLAMYDOSPORES

Sludge Concentration Before Incineration (mg sludge/g agar)	Percent of Spores in Each Category* †			
	0	1	2	3
0	3.2	12.8	7.2	76.8
0.01	6.4	10.4	7.6	75.6
0.1	5.2	14.0	8.8	72.0
1.0	4.0	15.6	10.8	69.6
10.0	16.0	78.0	6.0	0.0
20.0	21.6	70.4	6.8	1.2
100.0	19.6	74.0	6.0	0.4

* Determinations based on 10 replicate plates containing a minimum of 25 spores.

† 0 = ungerminated spores; 1 = single germ tube produced, no hyphal branching; 2 = single germ tube produced, some hyphal branching; 3 = extensive hyphal branching from germ tube.

TABLE 36. ANALYSES* OF NINE MUNICIPAL SEWAGE SLUDGES

Element	Location - Treatment+								
	C - Z	Cl L/F	D - 1	GH - An	LW - L/F	M - Act	MV - An	NO - Z	Wo - An
	(µg/g)								
N	19400	26000	35000	28200	19000	67200	29000	22600	27400
P	25800	20000	18000	37500	24100	12000	28000	59400	17300
K	1300	255	1250	2900	1400	4500	702	1000	2300
Ca	51000	92000	-	38300	172900	7000	22700	42800	23300
Mg	3900	2940	-	4500	4800	3300	3400	3500	4200
Na	479	604	-	1774	788	1074	1370	482	529
Fe	23900	30700	-	33800	48600	37900	11600	17300	17300
Al	8200	4550	-	35100	9800	6900	35800	68700	13500
Mn	507	302	-	641	925	166	370	1430	317
Zn	6460	2250	2790	1134	5860	927	820	980	2950
Cd	104	318	91	21	11	121	6	14	99
Cu	630	720	860	2990	329	371	6080	743	800
Ni	389	680	550	3750	45	56	6250	35	132
Cr	2131	240	180	5088	279	5715	15300	94	1418
B	48	107	-	107	97	96	43	39	41
Pb	160	216	63	211	148	456	36	168	993
Hg	46	36	-	88	43	60	12	125	993
Mo	23	13	-	35	18	22	26	29	44
O. M. (%)	62	61	50	23	15	79	40	36	45

* Total content after digestion in a 4:1 mixture of conc. HNO_3 and 70% $HClO_4$. Analysis by plasma emission spectroscopy. Nitrogen analysis by the Kjeldahl procedure; organic matter (O. M.) by wet digestion with $H_2Cr_2O_7$ (Walkley-Black).

+ Canton, OH, Zimpro process; Cleveland, OH (Southerly Plant), lime-ferric treatment; Detroit, MI, primary treatment sediment; greenhouse mix of anaerobically digested sludges from Mount Vernon and Lakewood, OH; Lakewood, OH, anaerobically digested and lime-ferric treated; Milwaukee, WI, activated sludge ("Milorganite"); Mount Vernon, OH, anaerobic digest; North Olmsted, OH, Zimpro Process; Wooster, OH, anaerobic digest.

TABLE 37. SOIL ANALYSES FOR UNTREATED RESEARCH PLOTS AT THE SECREST, DUNHAM, AND ZANESVILLE STATE TREE NURSERY SITES

Location	N*	pH	CEC	P+	K	Ca	Mg
			(meq/100 g)	(kg/ha)			
Secrest Road	13	6.7 ± .35§	10.9 ± 1.4	428 ± 106	543 ± 54	2850 ± 627	586 ± 97
Dunham Farm	25	5.1 ± .21	17.9 ± 6.4	48 ± 40	250 ± 102	2397 ± 2363	432 ± 636
Zanesville	10	6.5 ± .13	7.5 ± 0.5	119 ± 37	300 ± 35	2577 ± 214	182 ± 21

* Number of analyses per site.

+ Bray #1 - extractable P, other elements by $NH_4C_2O_2H_4$.

§ Standard deviation.

TABLE 38. ANALYSES OF SOILS AT THE SECREST SITE AFTER TREATMENT WITH VARIOUS RATES OF CLEVELAND SLUDGE

Rate	pH	EC*	P+	K	Ca	Mg	O. M.‡
(MT/ha)		(meq/100 g)	(kg/ha)				%
0	6.8 A	9.0 A	520 AB	504 A	2703 A	576 A	3.8 A
11	7.1 B	8.5 A	470 A	491 A	2671 A	553 A	3.5 A
22	7.3 BC	8.8 A	454 A	474 A	2658 A	568 A	3.2 A
45	7.1 B	9.8 A	412 AB	497 A	3147 A	506 A	3.9 A
90	7.4 C	12.8 B	666 B	435 A	4553 B	540 A	3.7 A
180	7.6 D	16.5 C	587 AB	469 A	6205 C	568 A	4.8 B

* EC = cation extractable with $NH_4C_2O_2H_4$.

+ Bray # 1 P.

‡ Organic matter oxidizable with $H_2Cr_2O_7$ (Walkley-Black).

TABLE 39. CHEMICAL ANALYSES OF NURSERY$^+$ SOILS TREATED WITH VARIOUS RATES OF DETROIT OR MOUNT VERNON SLUDGE OR NH_4NO_3 IN THE SUMMER, 1980

Treatment	pH	P*	K	Ca	Mg	CEC	O.M.
		kg/ha				(meq/100 g)	%
Initial	6.5	125	314	2692	213	7	-
None	6.6	116	307	2410	186	6	3.1
120 kg/ha N	6.5	115	252	2457	200	6	3.0
35 MT/ha Detroit	6.5	151	274	2504	195	6	2.8
80 MT/ha Detroit	6.6	243	274	2656	192	7	3.3
200 MT/ha Detroit	6.1	281	270	2761	197	7	4.8
35 MT/ha Mt. V.	6.7	146	243	3042	228	8	2.8
80 MT/ha Mt. V.	6.7	288	278	3007	230	8	3.4
200 MT/ha Mt. V.	6.9	352	222	3803	230	9	3.3

* Bray #1 extractable P.

+ Zanesville State Tree Nursery.

TABLE 40. VOLUME, DEPTH, SURFACE AREA, AND CONTAINER DENSITY FOR THIRTEEN CONTAINER TYPES

Container Type‡	Volume	Depth	Surface Area	Density +
	liter	cm	cm^2	$\#/m^2$
Book - 11*	0.17	13	15	527
Book - 22	0.35	19	19	301
Book - 45	0.74	23	32	205
Styroblock - 7	0.12	23	8	764
Styroblock - 21	0.34	15	29	215
Band - 8	0.37	25	15	689
Band - 7	0.34	18	19	527
Band - 6	0.66	25	26	388
Band - 5	0.66	18	27	269
Tarpaper - 8	0.33	23	18	689
Tarpaper - 6	0.66	25	26	308
Tube - 10	0.16	20	10	527
Tube - 40	0.66	25	28	215

* Numbers indicate volumes (in^3) of tubes, bands, and styroblocks, or numbers per linear foot of bands or tarpaper containers.

+ Number of containers that can be placed in $1 m^2$.

‡ Books from Spencer Lemaire, Edmonton, Alta., Can.; Styroblocks from Silvaseed Co., Roy, WA; Paper Bands from Monarch Manufacturing, Salida, CO; Tarpaper bands were handmade; Tube - 10 "Conetainers" from Poly-cast Plastics, Beverton, OR; Tube - 40 "Deepot" from J. M. McConkey Co., Sumner, WA.